

ИЗВЕСТИЯ
АКАДЕМИИ НАУК СССР
СЕРИЯ ГЕОЛОГИЧЕСКАЯ

IZVESTIYA AKAD. NAUK SSSR

SERIYA GELOGICHESKAYA

960

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No. 12, December

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TWENTY-FIFTH YEAR OF PUBLICATION

Technical Editor - V. Ya. Karasev

T-13976. Approved for printing November 16, 1960.

Circulation - 3,400 copies. Order 3523.

Paper size 70 x 108-1/16

Paper 4

Printing sheets 10. 96+4

Publ. sheets 12. 6

Second printing office of the USSR Academy of Sciences Publishing House.
Moscow, Shubinskiy per., 10.

PALEOMAGNETISM AND ITS SIGNIFICANCE IN STRATIGRAPHY AND GEOTECTONICS^{1, 2}

by

P. N. Kropotkin

I. INTRODUCTION. STRATIGRAPHIC SIGNIFICANCE OF INVERSIONS IN THE EARTH'S MAGNETIC FIELD

In recent years, considerable interest has been noted in paleomagnetism, i.e., the residual magnetism in rocks acquired during their deposition and diagenesis or after crystallization from a magmatic melt. Paleomagnetism was discussed at several scientific conferences and symposia abroad [29, 56, 57] and in three domestic conferences called by the Commission on Magnetism at the U.S.S.R. Academy of Sciences.

Just as a fossil preserves evidence of past life, so do the residual magnetism vectors reflect the distribution of lines of force of magnetic fields of earlier epochs, i.e., a "magnetic fossilization". This allows a reconstruction of the history of magnetism and makes the inversions, these radical alterations in the magnetic field, world-wide bench marks on the geochronologic scale. It turns out to be possible to determine from the orientation of rock magnetism, sampled in different places, the later horizontal displacement of the continents with relation to the poles and to each other [12, 24, 36, 44, 45]. Theories of fixed position and mobility of the continents have long since been competing in modern geotectonics, ever since the appearance of early works by O. Ampherer, F. Taylor, and A. Wegener, in 1906-1915. The fixed-position thesis is based on an unalterable mutual arrangement of major structural elements of the earth's crust, while mobility (continental drift) assumes large horizontal displacements. E. Kraus [48, 49], an outstanding champion of modern mobility quotes Heraclites' dialectic premise, "Everything is flux and change". The results of paleomagnetic study are in fair accord with reconstructions of earlier continents, by A. Wegener,

E. Argan, and more recently by A. Du Toit, L. King, the well known geophysicist B. Gutenberg, and others, operating with geologic, paleoclimatic, and geophysical data [2, 5, 6, 7, 38, 42, 47].

The earth's magnetic field is known to correspond on the whole (90%) to that of a geocentric dipole now tilted 11° to the earth's axis. The geo-magnetic axis changes its position constantly, by describing irregular loops, ellipses, and circles about the geographic axis ([12], Figure 1).³ Direct observations of changes in declination D and inclination J (the angle between the field vector and the horizontal plane) for freely suspended magnetic needles, conducted for 400 years in London and Paris, have shown that the geomagnetic axis has made over two-thirds of the full circle about the rotation axis, during that time. According to modern views developed by J.I. Frenkel, M. Elsasser, Yu.D. Kalinin, and S. Runcorn, the main source of the magnetic field are convection or eddy movements of matter carrying an electric charge. They take place at the boundary between the core and the crust, possibly in upper layers of the liquid iron core, and are controlled by the so-called Coriolis force originating in the earth's rotation. This is what orients the magnetic field along the meridians [9, 28].

This, in conjunction with direct observations of D and J, leads to the assumption that declinations of the geomagnetic axis with relation to the rotation axis are mutually compensated so that its median position for a period of tens of thousands of years coincides with the rotation axis. For such a geocentric axial dipole, magnetic declination at any point on the earth's surface may be taken as zero, while inclination J is connected with geographic latitude by a simple equation, $\tan \phi = 1/2 \tan J$.

In paleomagnetic studies, statistical analysis

¹Paleomagnetizm i yego znacheniye dlya stratigrafi i geotektoniki

²Paper read at the Session of Geologic-Geographic Sciences, the U.S.S.R. Academy of Sciences, June 8, 1960.

³To avoid repetition, a number of figures published by the author in a 1958 article on paleomagnetism are omitted; however, that article is quoted here.

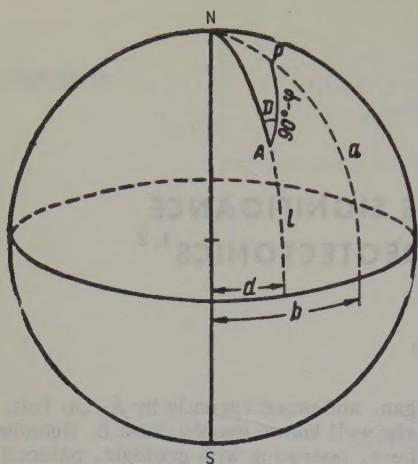


FIGURE 1. Determination of the position of the geomagnetic pole during the epoch by the inclination D and the deviation J of the vector of residual magnetization in rocks of corresponding age, taken at point A

P - position of the poles during the epoch, geomagnetic latitude ($\tan \varphi = 1/2 \tan J$). The position of P is determined graphically or by the formulas: 1) $\sin a = \sin l \cdot \sin \varphi + \cos l \cdot \cos \varphi \cdot \sin D$, where a and l are the width and b and d the length of points P and A .

of data is made for a great number of specimens (usually no less than a few tens) corresponding to different instants of geologic time; in this way the average value is computed for D and J of the magnetic vector, approximately corresponding to the orientation of lines of force for the axial dipole. With latitude φ known, arc of $90^\circ - \varphi$ can be measured off along the earlier magnetic meridian which forms angle D with the present geographic meridian in a given locality; in this way, the position of the pole with relation to that locality can be determined for the epoch corresponding to the rock origin (Figure 1). The pole coordinates are determined usually with the Wulf grid.

Runcorn's theory, as well as direct observations of the orientation of residual magnetism vectors in consecutive stratigraphic series reveal two possible comparatively steady positions for the geomagnetic axis about which it undergoes the above-described gyrations: when the north magnetic pole coincides on the average with the North Pole; and when it coincides with the South geographic Pole of the earth. Corresponding to the first is the negative or normal polarity; corresponding to the second is the positive or inverse. From time to time, inversion or a rebuilding of the magnetic field takes

place, with its entire orientation system reversed. Such inversions are known from spectrographic observations of magnetic fields of stars where they are brief; recently they have been discovered in the magnetic field of the sun.

Terrestrial inversions are separated by long periods, from half a million to tens of millions of years, and may serve, as mentioned before, as geochronologic markers. Thus an epoch from the very end of the Pliocene (Villafranchian) and taking in most of the Early Quaternary, was characterized by inverse polarity as indicated by Apsheronian deposits of Turkmenia, paleo-basalts of central France, and the contemporaneous basalts of Iceland, Sikhote-Alin, and New Mexico. It was followed by a period of normal polarity, which is still current (the Baku and Khozarian stages of Turkmenia; the valley basalts preceding the last glaciation in France; banded clays of Sweden and the eastern U.S.; younger basalts of New Mexico; the youngest basalts of Iceland, Aetna, etc.; [1, 24, 44]). Eight to fourteen alternating magnetic-stratigraphic zones of normal and inverse polarity have been discovered in the Pliocene and Miocene, below the Lower Quaternary inverted magnetic zone, by A. N. Khramov on Turkmenian red beds; by T. E. Einarsson, on Icelandic basalts; and by V. V. Kochegur, on Sikhote-Alin basalts. It was possible to map and correlate the rocks of individual zones with certainty. Late Cenozoic inversions of the magnetic field occurred at intervals of about 0.5 million years; the thickness of each zone was 200 to 400 m. For this reason, particular attention should be paid to a correct correlation of sections, as illustrated in Figure 2, because it is quite easy to make a mistake by skipping a zone.⁴

This difficulty is avoided when the inversions are separated by long periods of tens of millions of years. Thus according to data by R. Creer, T. I. Lin'kovskiy, and others, almost all of the Devonian is marked by an inverse polarity, with the normal-polarity rocks appearing only at the top of the Famennian. At the Devonian-Carboniferous boundary there appears to have been an alternation of shorter periods of opposite magnetic field orientations. Likewise, only the inverse magnetism has been noted in all known Lower and Upper Permian rocks, in the U.S.S.R., England, Norway, France, U.S., and Australia. According to A. N. Khramov, this long period of inverse polarity also takes in Early Tatarian time, i.e., the onset of the Triassic. As early as the Late Tatarian, however, there were two normal polarity zones separated by a thin inverse polarity zone, with another inversion in the Vetzugian Lower Triassic. All these zones

⁴Cores taken for paleomagnetic correlations should be marked right away, by an arrow pointing to the upper end.

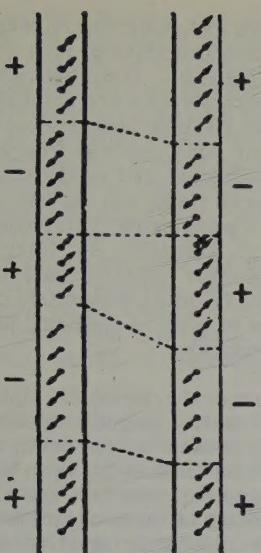


FIGURE 2. Diagram showing the correlation of two stratigraphic columns by the orientation of the vector of residual magnetization.

Magnetic-stratigraphic zones with normal magnetization -, with reverse magnetization +.

are correlative with the Volga-Ural sections [24]. About ten alternating magnetic-stratigraphic zones have been observed in Torridonian upper Proterozoic sandstones of Scotland, with some of them traceable over 10 or 20 km.

Magnetic inversions are now known from all systems or from their boundaries. It is possible that periods of rapid alternations in the magnetic fields were associated with a higher intensity of tectonic processes in the interior of the earth. The change itself takes up but about 10% of the time, with 90% accounted for by a stable field, either positive or negative. Judging from upper Cenozoic sections, the change takes tens of thousands of years. The regular change in D and J during that process, studied in most detail by A. Khramov and C. Momoset, appears to make possible an even closer correlation, down to shorter time intervals ([12], Figure 9; [23]).

All that suggests that the paleomagnetic method will be important in stratigraphic studies, and especially useful in correlating drilled sections in oil and gas fields. However, in dealing with extrusive rocks, we should keep in mind the possibility of autoinversion, i. e., the phenomenon wherein a rock, not affected by an external field, acquires a magnetic orientation opposite to the original. Autoinversion takes place in the presence of two differently magnetized mineral varieties dispersed in the rock, and with a

subsequent alteration of one of these two minerals, for instance of titanomagnetite to titanomaghemite. Such autoinversions, studied theoretically by L. Noel and obtained experimentally by T. Nagata and others, are of secondary importance in nature, affecting as they do only comparatively small volumes of volcanic rocks. In a vast majority of cases, extrusive rocks showing inverted polarity, besides sedimentary rocks for which an autoinversion mechanism is ruled out, have acquired it not as a result of that process but rather because the prevailing orientation of magnetic force lines then was opposite to what it is now.

II. RESIDUAL MAGNETISM AND ITS STABILITY IN ROCKS

Orientation of residual magnetism is characterized by declination D and inclination J of its vector while its intensity is characterized by the size of that vector. Three substantially different processes lead to the formation of residual magnetism in rocks.

Type One — Thermal magnetism originates in extrusive rocks as they cool off after crystallization. Ferromagnetic minerals formed in such rocks, magnetite, hematite, titanomagnetite, pyrrhotite, pyrite, etc., at temperatures close to the Curie point (560 to 675°C for magnetite and hematite) or somewhat lower, are readily magnetized in the direction of lines of force of the effective field and usually maintain this orientation for a long time. The original vector orientation has been preserved for one billion years in the Proterozoic of Lake Superior and for two billion years in the Bushveld gabbro-norites of South Africa. Judging from experimental data and from the results of A. G. Komarov's study of paleomagnetism in extrusive rocks, the degree of their magnetization decreases markedly for the first few tens of millions years, with subsequent changes being quite slight [10]. Intensive thermal magnetism has also been observed in contact-metamorphic rocks (hornfels, skarn) and in endogenic ore deposits (Angara-Ilim magnetite ore deposits, etc.).

Type Two of the residual magnetism vector originates in the formation of clastic sedimentary rocks, during the deposition of magnetized particles and at the initial stage of their consolidation. While settling in a body of water or being subjected to haphazard oscillations in an unconsolidated layer agitated by waves, all magnetic particles (grains of magnetite and of magnetite-bearing dark-colored minerals) become more or less oriented in the direction of the effective magnetic field. With all other orientation factors disorganized, all incidental deviations from such an orientation will be mutually compensating and the over-all orientation of residual magnetism in a great number of

clastic particles will reflect a quite definite orientation of the vector. This has been corroborated by the study of magnetism in recent sediments from the sea bottom as well as experimentally, by redeposition of magnetite sand in vessels with still water.

Type Three is expressed in magnetization of minerals in recrystallization of colloids (gels, etc.) and in precipitation of ferromagnetic minerals out of cold solutions. Unlike thermal magnetism, the intensive magnetization of this type originates at low temperatures, far removed from the Curie point and probably associated with the orientation of extremely small magnetic crystalline units or even molecules, in the very process of crystallization. This magnetization process, too, has been reproduced experimentally. This is the origin of magnetism in sedimentary iron and manganese ores, bauxites, the ferruginous cement of many sedimentary rocks (as in the formation of hematite in dehydration of iron hydroxides during diagenesis), and in various concretions. Even such slightly magnetic rocks as Lower Carboniferous light-gray calcareous shales, limestones, and calcareous concretions in the Llano Uplift in Texas show a well-preserved magnetic orientation of this type. A considerable magnetism of high stability (disturbing field, $H > 150$ oersteds) has been determined from our samples from Lower Cambrian red beds of China which carry finely-dispersed oxides of iron and manganese.

Thus, the residual magnetism vector is formed in entirely different ways, in extrusive, clastic, and chemically and biochemically precipitated sedimentary rocks. The coincidence of results obtained in the study of rocks with different types of magnetism is the best and an incontrovertible proof of their reliability. This coincidence points to a different orientation of magnetic field lines, in earlier geologic epochs. Subsequent consolidation and slight dynamometa-morphism of rocks alter but slightly the vector orientation.

The stability of magnetism is of prime importance in the study of paleomagnetism. It is related to the intensity of magnetic energy accumulated by microscopic, uniformly magnetized volumes of rock, the so-called domains, and it determines the preservation of the magnitude and orientation of the residual magnetism vector in relation to subsequent effects of temperature, a changeable external magnetic field, pressure, shocks, etc. Unstable rocks are remagnetized in accordance with lines of force of the present magnetic field while the stable ones maintain their magnetism for an indefinitely long time, provided their temperature does not rise too high and no sizable deformations take place. Metastable rocks occupy an intermediate position, in this respect.

Magnetostable rocks appear to predominate

among extrusive and sedimentary ferruginous rocks (chemically precipitated iron and manganese ores and bauxite). Prominent among clastic sedimentary rocks are unstable varieties, although almost all thick sections contain metastable and stable ones, such as fine-grained polymictic sandstones, red sandstones and shales, tuffaceous rocks and certain carbonate rocks, etc. On weathering, ferromagnetic minerals (magnetite, hematite, etc.) are replaced by limonite and other newly-formed minerals; because of that, residual magnetism of weathered rocks is low or gives a distorted picture of the vector orientation.

There are several criteria for stability. The presence of a residual magnetic orientation different from the present at that point, in its declination (D) or inclination (J), is in itself an indication of magnetic stability. Half a million years, the duration of the present field orientation, is enough time to remagnetize unstable rocks in the new direction. Sharp deviations in the vector orientation are often present in pre-Mesozoic magnetostable rocks. In Mesozoic and Cenozoic deposits, rocks with an inverse magnetization polarity must be regarded as stable to metastable.

A geologic method of determining stability in disturbed deposits was proposed by G. Graham and developed in more detail by A. N. Khramov. This method is based on correlating the data on the magnetic vector orientation in contemporaneous deposits, in samples taken from differently oriented beds, for example in the opposite limbs of an anticline (Figure 3). In

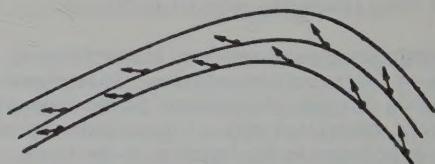


FIGURE 3. Diagram of the orientation of the vectors of residual magnetization in magnetically stable rocks forming an anticline (profile).

stable rocks, the magnetic vector is inclined everywhere at the same angle to the bedding surfaces. In unstable rocks, on the other hand, it has approximately the same orientation, throughout the disturbed rock, namely in conformity with the present magnetic field.

After a correction for the dip of the beds, values of D and J for areas of different rock occurrence are about the same for all magnetostable rocks. The correction is usually introduced graphically, by means of Wulf's grid, i.e., the stereographic projection; or the Schmidt grid, i.e., the equal-area projection

used in petrotectonic studies. As demonstrated by G. Graham, this method of correction of dip leads to erroneous results when applied to highly disturbed rocks (with dips over 30 to 40°) or to relatively plastic rocks such as disturbed limestones. In disturbed rocks, the spherical volumes are not merely rotated but also transformed into elongated or oblate deformational spheroids; individual grains are rotated in aplanar-type flow; and the result is an appreciable distortion of the vector orientation. It appears that, in this process, the vector assumes a position more conformable with the axial plane of folds than in a simple rotation at an angle equal to the dip of the beds.

The so-called method of remagnetizing circles, worked out by A. N. Khramov, is based on the study of metastable and unstable rocks as well as of the stable ones. It is possible to determine with this method the vector's position at the time of the rock formation, even when there are no completely stable rocks in a section [23].

Laboratory methods of stability determination are based on the effect of stable or permanent magnetic fields of various intensities, on rocks under study; the effect of temperature; etc. According to G. N. Petrova, magnetostable rocks are usually characterized by $H > 40$ oersteds of the disturbing field; with $H > 80$ oersteds, they maintain the magnitude as well as the orientation of the original magnetism. With $H = 10$ to 40 oersteds, the rocks may be regarded as metastable, while with $H < 10$ oersteds they should be regarded as unstable. The intensity of the present magnetic field is about 0.5 oersteds. However, geologic methods have demonstrated that rocks with $H < 10$ oersteds are commonly stable.

Samples for paleomagnetic study are taken by knocking off or cutting specimens of fresh rock out of outcrops and by cutting them, in the laboratory, into cubes with sides of 2.5 or 5 cm. It is desirable to have a bedding surface for at least one side of the specimen; the strike and dip directions are marked by a diamond or lead pencil or else drawn on labels. The samples are oriented with a mining compass. The strike and dip of beds should be accurately recorded. In addition, the magnetic declination should be known for the sampling point, for a corresponding correction. Samples of strongly magnetic rocks creating local anomalies should be oriented by the sun (e.g., by the shadow of a plumb line) or by other methods.

Magnetometric measurements in laboratories are made with astatic magnetometers (such as Dolginov's modified magnetometer) or with the more sensitive dynamo-magnetometers, called rock generators.

III. DETERMINATION OF THE POSITION OF THE POLES BY PALEOMAGNETIC DATA

After a large number of measurements (no fewer than ten) on stable rocks have been made to determine that the scattering of points with declination D and inclination J is not excessive on the diagram, the average value of D and J can be determined with adequate certainty, and then the position of the geomagnetic pole for the corresponding geologic epoch (Figure 1). Ordinarily, an analysis of statistical data by Fisher's method provides, in addition to the average value of D and J, the radius of the so-called confidence circle encompassing that area about the average computed position where the probability of finding the pole is greater than 95%, for a given scattering of data. The degree of scattering, in its turn, is characterized by a special factor.

The results of almost all such determinations extant, as illustrated in Figure 4, show that despite the utterly different origin of residual magnetism, contemporaneous rocks, both extrusive and sedimentary, exhibit similar values, provided they come from the same region. Examples are Permian rocks of Europe, as established from 11 determinations of polar coordinates [23, 24, 44]; Upper Carboniferous and Permian rocks of Australia, from four determinations [45]; and Upper Triassic rock of the U.S., from four determinations [37]. All of the 11 determinations on sedimentary and extrusive Permian Rocks of Europe (Norway, southern England, Scotland, France, West Germany, the Volga-Ural province) show the polar coordinates of 36 to 46° North latitude (with the exception of a single determination) and 162 to 185° East longitude, with a deviation from the average of not over 8° of the great circle arc. The position of the Upper Carboniferous and Lower Triassic pole falls in that vicinity.

The position of the pole, as determined from Pliocene and Quaternary rocks of all continents turns out to be close to the present position, differing from it by not more than 5 or 10°. The position of the Late Carboniferous and Early Triassic pole was not far from there. Thus, from the magnetism of Late Tertiary basalts of Canada and the northwestern U.S., the pole falls at 84 to 87° N; from similar basalts of Iceland, at 77 to 88° N; of Africa, 81.5° S; Australia, 86° S; and Japan, 79° N. Arenaceous deposits of the Baku stage (N_2-Q_1) in Turkmenia give the pole position as 81° N; banded clays of Sweden, formed in a period from 1100 BC to 750 AD, give it at 88.4°; post-glacial lavas of Iceland, 86°; and equally young Japanese lavas, 81 to 86° N. The magnetism of Etna's lavas, poured out between 394 BC and 1911 AD, corresponds to an average position of the pole at 86.3° N [24, 44]. Such an excellent coincidence of results suggests that with a large number of data the position of the pole can be



- | | | | | | | | |
|---|---------------|---|----------------|---|---------------------------|---|--------------------------------|
| 1 | Igneous rocks | 2 | Volcanic tuffs | 3 | Clastic sedimentary rocks | 4 | Chemical and Biochemical rocks |
| 2 | □ ○ | 3 | □ ○ | 4 | □ ○ | 5 | □ ○ |
| 3 | □ □ | 4 | □ □ | 5 | □ □ | 6 | □ □ |
| 4 | △ △ | 5 | △ △ | 6 | △ △ | 7 | △ △ |
| 5 | △ △ | 6 | △ △ | 7 | △ △ | | |
| 6 | △ △ | 7 | △ △ | | | | |
| 7 | △ △ | | | | | | |

FIGURE 4. Position of the north pole, according to the data on paleomagnetism of rocks:

1 - North America; 2 - Europe; 3 - Siberian platform; 4 - China and Japan; 5 - India; 6 - Africa; 7 - Australia. Ages of the rocks: C - Cambrian; O - Ordovician; S - Silurian; D - Devonian; M - Lower Carboniferous (Mississippian system); C - Middle and Upper Carboniferous; P - Permian; T - Triassic; J - Jurassic; K - Cretaceous; E - Paleogene (mainly Eocene); N - Neogene; Q - Quaternary.

determined within 5 to 10°, for more ancient ages, as well.

As noted by S. Runcorn, E. Irving, T. Nagata, and other magnetologists, earlier geologic periods are characterized by two regularities in the position of their poles [36, 44, 53, 55]. First, Paleozoic, Mesozoic, and Lower Tertiary rocks of all regions show that the position of their poles differs from the present one roughly in proportion to their age. Second, the loci of geomagnetic poles differ depending on determinations made on rocks from different regions, with the difference being particularly conspicuous in longitude. Six individual curves of polar movement are shown in Figure 4, as determined from the magnetism of rocks in North America (squares), Europe (circles), Japan and China, Africa and Madagascar, India, and Australia (triangles). The polar determinations from Triassic trap-rocks of Siberia (diamonds) are close to the curves from North America and Europe. The difference in the curves' position is interpreted usually as the result of a drift of the continents relative to one another [23, 34, 44]. For instance, the completely opposite trends of polar loci, as obtained from the magnetism of Hindustan rocks, on one hand, and from Europe and North America on the other, may be regarded as the result of a rapprochement of Hindustan and these continents, in the late Mesozoic and Cenozoic, if it took place approximately along the meridian (Figure 5). A countermovement of Hindustan with relation to the rest of Eurasia has long since been suspected from geologic data, in explaining the Himalayan structure [11]. The rate of the continental drift, determined from paleomagnetic data (2 to 6 cm per year) turns out to be of the same magnitude as the rate of the contemporaneous horizontal displacement as determined from repeated geodetic triangulations in mobile belts of the crust (0.2 to 40 cm per year) and from a correlation of astronomic latitudes (6 to 15 cm per year).

Paleomagnetism gives only the latitude and the bearing of the pole, with relation to rocks under study, at a given point of the crust. For this reason, a more rigorous analysis shows that some uncertainty remains in the reconstruction of an earlier mutual position of the continents. This uncertainty, not always subject to elimination, rests on the fact that a

displacement α in the polar position along a great circle arc, as computed from D and φ (Figure 1), may be caused either by a rotation of the given segment of the crust, by angle β or by its displacement over a distance $L = \gamma \cdot R$, where γ is the great circle arc, in radians, and R is the radius of earth. It can be demonstrated that a displacement of magnitude α , in the computed position of the pole is never larger than β (in the first instance) or γ (in the second). It follows that large discrepancies in the position of the pole, such as 75° of the great circle arc, for upper Paleozoic rocks of Australia and Europe, have originated either in a rotation of one of these continents at an angle greater than 75°, with relation to the other, or as a result of their having drifted relative to one another, over a distance of 8300 km, which corresponds to 75° of a great circle arc; or else they are due to a combination of sizable rotations and drifts.

A check of these conclusions and a geologic evaluation of the accuracy of paleomagnetic data can be done in two ways: by a paleoclimatic correlation and by a correlation of geologic data on the mutual position of the continents.

IV. PALEOMAGNETISM, PALEOCLIMATES, AND ASTRONOMIC DATA ON RECENT CHANGES IN LATITUDE

Obviously, the changes in latitude φ and declination D in any area, as computed from paleomagnetic data, should correspond to paleoclimatic data on changes in latitude and orientation of climatic zones; they also should give the values of φ for the close of the Cenozoic, corresponding to the present latitude of that area. A correlation of paleomagnetic and climatic data for England and the U.S. was made by E. Irving. His curves demonstrate that during the entire Paleozoic and Triassic, these regions lay in low magnetic latitudes, from 30° South latitude to 30° North latitude for England; from 20° S to 30° N for the eastern part of the U.S.; and from 0° to 30° N, for the western part of the U.S. [29].⁵ The distribution of warm coral seas in the early Paleozoic; the salt and

⁵For these curves see [12], Figure 8.

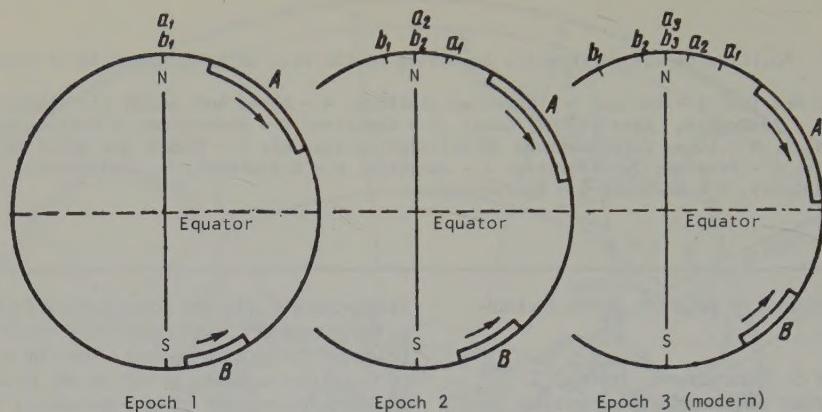


FIGURE 5. The formation of intersecting curves of movement of the pole (a_1 , a_2 , a_3 , and b_1 , b_2 , b_3) as a result of the movement of two blocks of the earth's crust (A and B) toward each other, and moving approximately along the meridian.

a_1 , b_1 , a_2 , b_2 , a_3 , b_3 are the positions of the poles in epochs 1, 2 and 3, as may be determined by the paleomagnetism of the rocks of the continental blocks A and B.

gypsiferous deposits of the Devonian and Permian; and of a hydrophilic tropical flora of the Early Carboniferous, all are in accord with this evaluation of the position of England and the U. S. with relation to the equator. A definite cooling is indicated for England and even more so for the U. S., beginning with the Jurassic and Cretaceous, with their climate gradually approaching present conditions; this is also in accordance with paleomagnetic data.

For Eastern Europe, we have a set of paleogeographic maps, from Middle Devonian to Early Permian, recently published by N. M. Strakhov. He asserts on the basis of extensive material, that climatic conditions of the Paleozoic and Mesozoic underwent a regular change here. Assuming a steady pole, these changes correspond to a displacement of the Russian platform from the south equatorial zone to the north temperature zone, accompanied by a clockwise rotation, for several tens of degrees. N. M. Strakhov writes as follows of northwestern Eurasia, "... a Caledonian climatic plan still prevailed during the Middle Devonian. The tropical zone trended at a sizable angle to present latitudes, from Medvezhiy Island across the Urals to the Altay and farther on to China. The north arid zone passed north of there, over the Siberian Platform and the islands of the Arctic Ocean, and on to northeast Asia. The south arid zone passed across the Russian platform and on to Central Asia. In the Late Devonian, this Caledonian climatic plan gradually gave place to the Hercinian... Toward the Middle Carboniferous, with the rebuilding completed, the humid tropical zone was located in southern Europe; the north arid zone, over the Russian platform and in Central Asia; and the south arid zone, in Brazil and North America. This plan persisted to the end of the

Permian, with a new shift of the humid tropical and the two arid zones during the Triassic, still farther to the south. During the Early Jurassic the onset of the Alpine climatic zonation, which is still going on, became discernible" ([20], p. 17). "The presence of a certain mobility in the lithosphere, following the major folding epochs, would be the best and most probable explanation, in our opinion, for such substantial and abrupt changes in the general climatic conditions as that observed in northwestern Eurasia, at the Paleozoic-Mesozoic boundary" ([18], p. 14). This change in the orientation of Eurasian climatic zones, noted by N. M. Strakhov as early as 1945, was subsequently confirmed by Yu. M. Sheynman and L. B. Rukhin [17].

Paleomagnetic data are in accord with these conclusions. Thus, magnetism of Devonian bauxites (D_1^1) from the northern Urals shows, according to N. A. Ivanov, that this area lay at approximately 7° N ($J = 15^\circ$), not far from the equator, while the magnetic parallels trended $N - 23^\circ$ - W, i. e., corresponding to the equatorial zone of N. M. Strakhov's Middle Devonian climatic map, where it is shown to pass directly through these bauxite deposits. It is possible to determine from Strakhov's maps the approximate position of the pole with relation to the Russian platform: for the Middle and Late Devonian, it falls at about 16° N and 175° W. This is not too far from the geomagnetic pole position determined as an average of residual magnetism of Devonian rocks of Europe (27° N, 160° E).⁶

⁶According to T. I. Lin'kova and N. A. Ivanov (Third Paleomagnetic Conference, 1959; also English data [36]

The position of the Permian pole is determined as 60° N, 175° W, assuming that the median line of the Kungurian arid zone in Europe and Kazakhstan coincides with the North 30° parallel of the Early Permian. The corresponding pole lies in the northwestern Pacific, not far from its median position as determined from European rocks (44° N, 170° E). Consequently the same rapprochement of Eastern Europe and the North Pole, and its clockwise rotation, can be inferred from paleoclimatic data for the Devonian, late Paleozoic, Mesozoic and Cenozoic.

Attempts at reconstructing the path of the polar migration were made by D. Krichgauer, in 1902,¹ by L. B. Rukhin, in 1955-1959; and quite recently by N. M. Strakhov [17, 19, 50]. All three authors place the early Paleozoic North Pole in the central part of the Pacific (16° N, 172° W, according to N. M. Strakhov and L. B. Rukhin; 14° N, 124° W, according to D. Krichgauer). The coordinates from paleomagnetic data for European lower Paleozoic rocks are 1 to 45° N and from 151° E to 177° W; from North American rocks 0 to 35° N and 138 to 158° E, in the Central Pacific, somewhat to the west. Recorded by both is a 75° shift of the pole with relation to these continents, which also follows from the paleoclimatic data.

Inasmuch as these authors regarded the disposition of the continents as immutable, they had to draw the late Paleozoic equator through India and Australia where there is evidence of a major glaciation. Passing over this inconsistency, for the time being, we note that the path of the pole's migration corresponds approximately, according to N. M. Strakhov and L. B. Rukhin, to a certain "resultant" median curve which can be imagined by combining paleomagnetic curves of the polar migration, obtained from paleomagnetism of Eurasian (without India, i. e., considering only the European and Sino-Japanese curves), North American, and African rocks.

We correlated paleoclimatic data for the Paleozoic of Eurasia (without India) and North America, disregarding the possible shift of these continents with relation to one another but drawing the magnetic equator to correspond to European paleomagnetic data, in Eurasia; and to American data, in North America (Figure 6). Our map, like the paleoclimatic maps of those authors, shows distinctly that the Devonian, Carboniferous, and Permian arid zone passes from Europe (Emba, Volga-Ural province, Western Europe), across the Solikamsk area

and Nordvik Point in northern Siberia (salt - D), to Spitzbergen (gypsum and anhydrite - C₂; dolomites and red beds - C₃), on to northeastern Greenland (dolomites and gypsum - C₃), and northern Canada (gypsum - D, in Elsmere Island, 82° N; gypsumiferous Devonian of the MacKenzie River). By its Carboniferous and Permian saline facies and red beds, this belt is traceable still farther on, to the western part of the North American platform and the Gulf of Mexico. The subtropical aspect of the flora of Lower Carboniferous coal measures in Spitzbergen Island and Western Europe is also in harmony with this zonation scheme. A cold to temperate zone of northeastern Asia with its Lower Permian coals and a Tunguska flora fringes the Permian polar provinces, while its boundary with the arid zone coincides approximately with the 35 to 40° N parallel of that time.

Thus, all paleoclimatic riddles of the Arctic and Siberia are solved in the light of paleomagnetic data.

An even more interesting picture looms in a correlation of paleoclimatic and magnetic data from India, Australia, Africa, South America, and other provinces of the southern hemisphere, components of the Paleozoic Gondwanaland. Evidence of Silurian and Devonian glaciations are known here from the eastern part of the South American Platform, the Andes of northwestern Argentina, and South Africa, while a warm climate prevailed in Australia. In the late Paleozoic (Late Carboniferous, Early Permian), a thick continental glacier covered the southern half of Africa, Madagascar, southeastern South America, Falkland Islands, and a considerable part of the Indian and Australian shields [7, 8, 30, 51].

In India, "... a glacier covered Rajputana and the central India Highlands. The glaciers appear to have moved toward the Salt Range. A boulder bed, a consistent and very typical marker horizon in the Hindustan Peninsula, has a thickness of 15 to 30 m" ([11], pp. 172, 195). In southeastern Hindustan, the glaciers descended in huge tongues into graben-like depressions of the Godawari and Mahanadi Rivers, which were filled with a series of Gondwana marsh-lacustrine deposits.

In Australia, Lower Permian glacial deposits are known from the west, southeast, and northwest (continental tillites, etc.). In the Carnarvon basin and other west Australia downwarps, the Permian glacial complex opens with glacial marine and lacustrine beds; fluvio-glacial deposits associated with brackish-water facies are known from the York Peninsula. Also present in southeastern Australia are older Upper Carboniferous lacustrine glacial banded clays [43, 58].

These facts show that over an immense area

¹D. Krichgauer's map is cited in the well-known book by A. Wegener ([5], p. 73) and in B. Guttenberg [6]. The locus of the pole, according to D. Krichgauer, L. B. Rukhin, and N. M. Strakhov, is given in Figure 4.

along the coast of Australia and India, a glacier descended to coastal plains and even to the shore ([26], pp. 148, 153). A *Glossopteris* flora is present here as it is in all other parts of Gondwanaland affected by glaciation. Unlike the tropical European fauna, it suggests a

comparatively cool climate, is poor in species, and contains woody forms with well expressed annual rings. For this reason, the Gondwana students are unanimous in assuming a cold, from temperate to polar, climate for those provinces, in the late Paleozoic. Geologic and paleobotanical

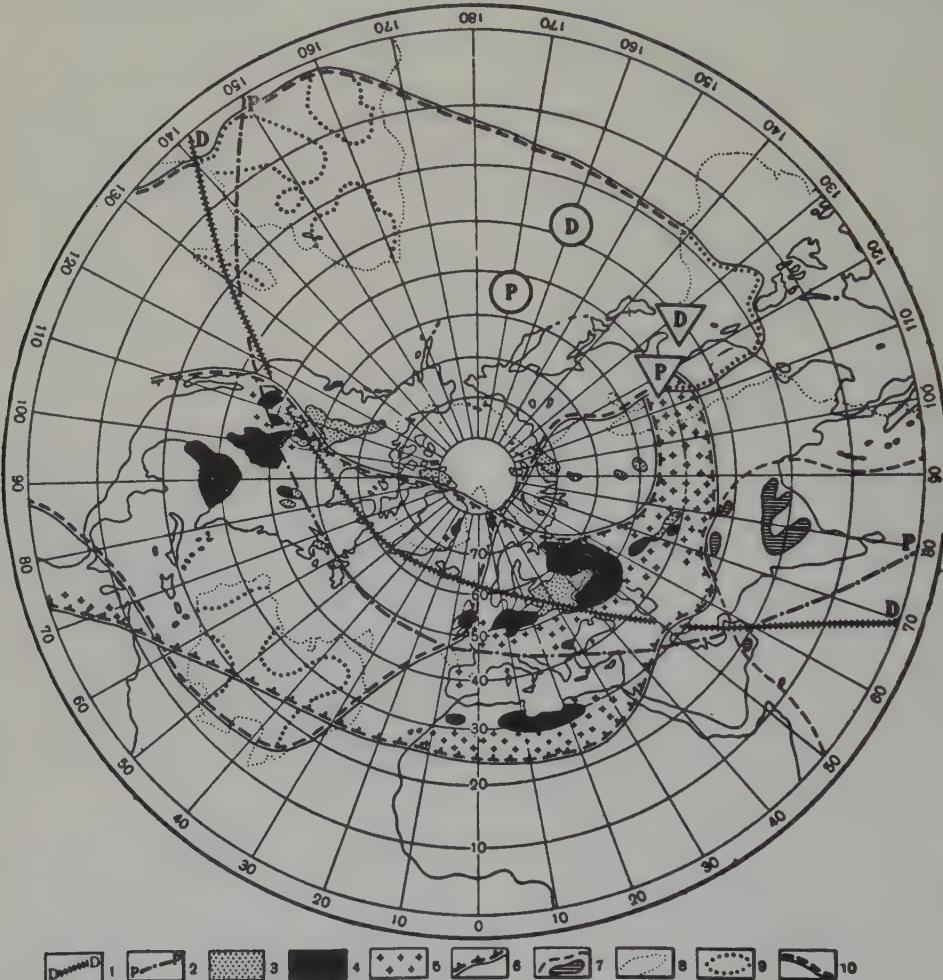


FIGURE 6. Position of the North Pole and the Equator, based on paleomagnetic data of the rocks of Europe (circles) and North America (triangles); distribution of arid facies of the Devonian and Upper Paleozoic in the Northern Hemisphere, and of the late Paleozoic glaciation in the Southern Hemisphere.

Average position of the pole: D - Devonian (for the U.S.A. the position of the Devonian pole was obtained by interpolation from the values for S and C1); P - Permian and Late Carboniferous; 1, 2 - position of the Equator in the Devonian [1] and the Late Carboniferous and Permian [2], according to the paleomagnetism of North American and European rocks (after Creer, Irving and Runcorn, with corrections); 3 - saline and gypsum deposits of the Devonian and Lower Carboniferous; 4 - same of the Upper Carboniferous and Permian; 5 - red continental deposits of the Upper Carboniferous and Permian, with admixtures of NaCl and CaSO₄; 6 - limit of distribution of the halogenic and red arid formations of the upper Paleozoic (C₃ - P) in the Northern Hemisphere (in the intervals between the zones containing these deposits there are deposits of tropical humid zones); 7 - upper Paleozoic glacial deposits and the boundary of the area of late Paleozoic glaciation in India; 8 - outlines of the continents of the Southern Hemisphere in the antipodal projection into the Northern Hemisphere; 9 - distribution of upper Paleozoic glacial deposits (antipodal projection); 10 - limits of the area of the Gondwana late Paleozoic glaciation in the Southern Hemisphere (antipodal projection).

ta do not support in any way the view of N. M. Rakhov and L. B. Rukhin that Australian and dian glaciers were but local glaciations in a opical zone.

As noted by S. N. Bubnoff it is "in the realm climate that there are many facts which cannot be explained except by continental drift. Here belongs the spreading of a Permian glaciation whose evidence is known from South Africa, northern India, and some other places. Some of these localities are 90° apart, so that when one of them was located near the pole, the other would fall near the equator, i. e., in an area where glaciation is impossible. This is one of the facts unexplainable on the basis of ism (i. e., a fixed position of the continents)" [3], p. 176). Similar views on the necessity for accepting mobility of the continents have been expressed by M. Schwarzbach, B. L. Chkov [14], M. Gignoux ([8], p. 241), K. Curlen [30], and others.

In South America, the movement of late Paleozoic glaciers, judging from striations, c., was from the east, from the present Atlantic, i. e., from provinces where geophysical studies show the absence of a continental thrust and a wedging-out of its granite layer. Now, glacial erratics consist mostly of granite, gneiss, and motley quartzites, similar to African Precambrian rocks. These interesting facts can be interpreted only by a reconstruction similar to that presented in Figure 7 [1]. According to R. Maack, tongues of Transvaalian and Greekvalendian glaciers of South Africa penetrated the present South America. A similar problem exists in relation to the source of granite-gneiss boulders (as

well as older Devonian clastic material) brought to South Africa from the southeast. L. King solves this problem by assuming the proximate position of Antarctica and Africa, during the Paleozoic [47].

That epeirophoresis is not to be denied is even more obvious from the wide scattering of areas of late Paleozoic glaciation throughout the southern hemisphere and India, as well as from correlating these paleoclimatic data with the outlines of upper Paleozoic arid facies in the opposite hemisphere, as shown in Figure 6. As long as the poles are always opposite to each other, with points of the equator and the tropical humid zone, in both hemispheres, corresponding to one another, and the same is true for corresponding points in the north and south arid zones, the correct analysis of paleoclimatic data is best made by superimposing the antipodal maps.

Superimposed on such maps are points at the opposite ends of a diameter passing through the center of the earth. In Figure 7, the outlines of the southern continents and of their late Paleozoic glaciation are projected on the northern hemisphere, along with a general outline of the major continental glaciation in the southern hemisphere of that time. If the South Pole was in the center of this area, the North Pole should have been approximately at 40° N and 110° W, not allowing for continental drift. Now, instead of showing evidence of glaciation, this is an area of arid facies, Upper Carboniferous gypsum, anhydrite, and salt, in Utah and Colorado; and thick Permian salt formations in New Mexico and Texas. Generally speaking, most of the upper Paleozoic arid province with

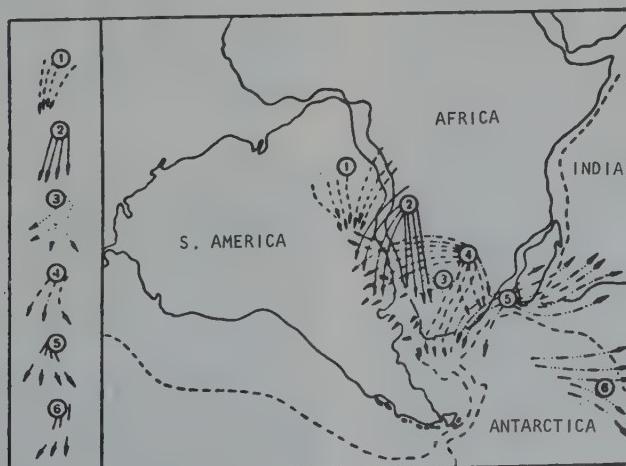


FIGURE 7. Reconstruction of the relative positions of South America, Africa and the other parts of Gondwanaland during the Late Paleozoic glaciation

Arrows show the direction of movement of the glaciers; figures indicate the centers of their distribution (after Maack).

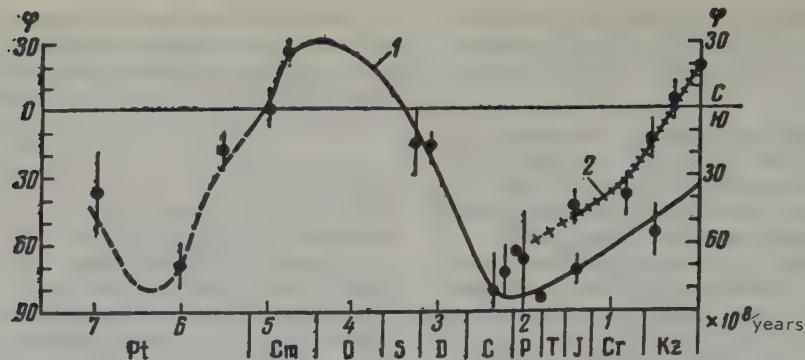


FIGURE 8. Change in the magnetic latitude of southeastern Australia (1, area of 35° S lat. and 145° N long.) and Hindustan (2, area of Bombay).

Vertical lines with dots indicate the limits of possible error in determining the geomagnetic latitude.

its facies of gypsiferous and salt-bearing beds, from northwestern Europe and Spitzbergen to the southwestern U. S., fall into the projection of the polar Gondwana province, up to its central part, a fact utterly impossible on the basis of paleoclimatic data.

Results of the paleomagnetic study of Australian, Indian, and African rocks agree with the paleoclimatic data. Figure 8, borrowed from E. Irving, shows changes in magnetic latitude ϕ for southeastern Australia, from the Proterozoic to the present. Here, high values of ϕ (up to 70 or 84° S) occur twice: at the close of the Proterozoic and again in the Late Carboniferous and Permian. This is exactly where the glaciation data belong, thick upper Proterozoic (Rhipehan) in the Adelaide area and the above-mentioned more widely distributed upper Paleozoic marine and continental glacial deposits [45]. In the early Paleozoic and in the first half of the Devonian, Australia was located in the tropical and subtropical zones, between 30° S and 30° N, which also is in accord with geologic data on the climate (warm coral seas, dolomites, red beds). Evidence of Triassic, Jurassic, Paleogene, and Neogene volcanics of Australia and Tasmania shows a gradual decrease in magnetic latitude ϕ , from the end of the Paleozoic on, leading to the exact present geographic latitude of those places. Judging from paleobotanical and lithologic data, the climate underwent corresponding changes.

Plotted on the same map, from data of J. Clegg, E. Deutch, K. Radakrishnamurty, and P. Sahasrabudhe, is a latitude curve for the Bombay area, from paleomagnetism of Jurassic, Upper Cretaceous (lower flows), and Paleogene (upper flows) traprocks and Miocene acid tuffs.

Like the preceding curve, this one shows a drift of the continent from the South Pole and ends at a point corresponding to the present geographic latitude of these areas [35]. An extrapolation of the Indian curve back to the Permian suggests the late Paleozoic position of that area at 60 to 75° S; consequently, it could have undergone a glaciation.

Likewise, evidence of Upper Carboniferous and Lower Permian rocks in Rhodesia and Kenya shows that southeastern Africa of that time was located in high latitudes, while the values of ϕ from Upper Permian, Triassic, and Jurassic rocks are not that much different from the present ones. The distance between South America and the pole, in the Triassic, Jurassic, and Lower Cretaceous differed from the present one by not more than 20 to 30° [44].

Thus, it appears from paleomagnetic data that Australia, Africa, and India of the late Paleozoic were much nearer to the pole, and consequently to each other, than they are now. India and Australia drifted away from the pole in the Mesozoic and Cenozoic. The distance from the pole to Africa and South America changed little, during that time.

All these conclusions are in good accord with direct geologic data on climatic changes. Paleomagnetic data from all provinces except for Hindustan agree with N. S. Shatskiy's conclusion that the orientation of the equator and climatic zones with relation to the continents, toward the end of the Cretaceous, differed only a little from the present one. It is interesting to compare these data with the latitude changes determined astronomically for the last 50 years by the International Latitude Service and by such

bservatories as the Pulkovo which conduct systematic observations of latitude. These observatories are located along the 39° N parallel, Italy (Carlofronte), Japan (Mitsuzava), and the western U.S. (Ukiah). The change in the Ukiah Observatory latitude is the most significant. For instance, according to Ye. N. Brezko's computations, it increased by 0.0047" per year, on the average, between 1900 and 1934 [16]. The Pulkovo Observatory is 153.5° of longitude distant from the Ukiah station; i.e., on the opposite side of the northern hemisphere. Consequently, and with the continents steady, it should have about the same absolute value, but opposite in sign, in the secular latitude change. As a matter of fact, according to first order observations at Pulkovo, its latitude has not changed for the last 50 years, or has decreased by not over 0.00005" per year, on the average. Thus, these latitude changes must be regarded as the result of a systematic shortening of the distance between Pulkovo and Ukiah, by 10 to 15 cm a year, rather than as the result of a movement of the Pole with relation to the earth as a whole.

B. Vanach, Ya. D. Orlov, and G. Checcini attempted to determine the direction and rate of movement of the Pole with relation to three longitudinal stations, by assuming their relative position as constant [52]. It was determined that the Pole had been shifting for the last 50 years in the direction of 38 to 69° W, at a rate of 6 to 15 cm per year. This direction is not much different from the median direction of polar drift (approximately 35° W) which can be charted by summing up the American, European, and Japanese curves for similar drift in the Mesozoic and Cenozoic, as obtained from paleomagnetic data. The rate of the present movement of either the Pole or North America and Eurasia with relation to the Pole, as determined from astronomic data, is even somewhat higher than assumed from paleomagnetic data for the last 100 million years (2 to 5 cm annually, by American and European rocks).

V. PALEOMAGNETISM AND THE MUTUAL DRIFT OF THE CONTINENTS

The second way to check paleomagnetic data is, as already noted, to correlate them with geologic data on an earlier arrangement of the continents or of individual tectonic platforms and blocks. It is obvious without much demonstration that if an immutable mutual geographic position can be established from geologic data for two crustal segments A and B (such as platforms or continents), for a time interval from epoch X to epoch Z, then segments XZ of the polar drift curves obtained by rocks from A and B, should coincide within the limit of error, in a reconstruction of this mutual position.

It follows that if any segment of the crust may be selected for A and B, — as postulated by the fixed-position-of-continents hypothesis, while period XZ embraces the entire geologic history of the earth, i.e., if we take the extremes of the conditions given, then the curves constructed from paleomagnetism of rocks from all continents should coincide. In other words, there should be a single locus of the polar drift, corresponding to the position of the geomagnetic axis for the entire earth. This, however, is not the case. Despite the fairly large scattering, all determinations from rocks of the same region are definitely grouped along the individual curves mentioned above, shown in Figure 4 in about the same way as was done by S. Runcorn, E. Irving, E. Deutch, J. Clegg, and T. Nagata, from scantier data [29, 35, 53, 55]. This lack of coincidence of the curves and their difference by the quantity $\alpha = 25$ to 100° of the great circle arc, between the polar coordinates as determined from contemporaneous rocks, is well illustrated by data on the Upper Carboniferous, Permian, and Lower Triassic of Australia, Europe, and North America. The data on deposits in those provinces are adequate for a mutual control of paleomagnetic determinations by extrusive and sedimentary rocks. The lack of agreement in the Upper Carboniferous, Permian, and Lower Triassic from these continents far exceeds the possible error. It follows that it is impossible to interpret paleomagnetic data on the basis of a fixed position of the continents. For this reason, P. Bleekert, S. Runcorn, J. Clett, E. Irving, T. Nagata, A. Roche, P. Du Bois, A. N. Khramov, and other magnetologists, arrive at the concept of a considerable mutual shift of the continents.

In assuming that Europe and North America were welded together by the Caledonian and Hercinian foldings, at the close of the Paleozoic, and that their drifting apart began in the post-Triassic, we should anticipate that after a proper reconstruction, positions of the Permian and Triassic poles, as computed from European data, should coincide with those computed from North American data. Such reconstructions of the late Paleozoic North Atlantic structure were presented by A. Du Toit, E. Kraus (Figure 9), and S. Carey. S. N. Bubnoff, too, believes that the Norwegian-British orogeny was directly related to the caledonids of Greenland and Spitzbergen. "The Varanger Fjord zone continues to Spitzbergen. To the southwest, there is a possible connection with the folded Eleonora Bay formation of Greenland, which may be the northwestern limb of the Norwegian caledonids and a continuation of Scottish structures. This concept appears to support Wegener's ideas of continental drift" ([4], p. 109). Similar opinions are voiced by W. Holtedal.

A recent magnetic survey of the shelf, west of France, has shown that folded structures indeed continue latitudinally, as far as the



FIGURE 9. Reconstruction of the relative positions of North America, Greenland and Europe at the end of the Paleozoic Era (after E. Kraus, 1951).

1 - Precambrian crystalline shields; 2 - platforms; 3 - Caledonian folding; 4 - Hercynian folding; 5 - front of Caledonian and Hercynian folding; 6 - Appalachia and the ancient cores in the system of Hercynian structures; 7 - axes of Paleozoic orogenies; 8 - direction of the folds (their inclination, overturning, or direction of movement of thrusts); 9 - present positions of meridians.

continental slope, as anticipated in the mobilists' reconstructions. Farther to the west, in deeper reaches of the Atlantic, the so-called "granite layer", i.e., the folded basement, wedges out completely.

Figure 10, after E. Irving, shows that the best coincidence of the poles computed from upper Paleozoic and Mesozoic rocks of North America (confidence circles cross-hatched) and of Europe (circles blank) is achieved in the S. Carey reconstruction. Like the E. Kraus scheme, it assumes a more crowded earlier disposition of these continents than in the A. Du Toit plan [38]. The most recent studies by P. Du Bois as well as our own analysis from the latest data, with consideration given to the U. S. S. R. paleomagnetic determination, corroborate this conclusion and show that a coincidence of the curves for a time interval from Late Carboniferous to Late Triassic will be achieved through a rapprochement of North America and Europe, by 45° of longitude (about 380 km or 35° of the great circle arc). The split is marked by a system of Upper Triassic grabens on the east coast of the U. S., parallel

to the continental slope. This would mean an average rate of continental drift of 2 cm a year, hundreds of times lower than that postulated by Wegener.

Thus, the difference in the position of the poles, as computed from American and European data, is regarded by magnetologists as the result of a movement corresponding on the whole to a rotation of North America with relation to Europe, about a center coinciding with the present North Pole [36]. The discrepancy between the Indian and European—North American curves is in better agreement with the situation illustrated in Figure 5. These curves run opposite to each other, which may be regarded as the result of a rapprochement of the continents, with their relative movement occurring roughly along the meridian.

In an early explanation by E. Suess, the Himalayan structure is regarded as the result of a rapprochement of the central parts of Asia and the Indian Platform. This idea was subsequently accepted, on one form or another, by all students, both of the fixed-continent school

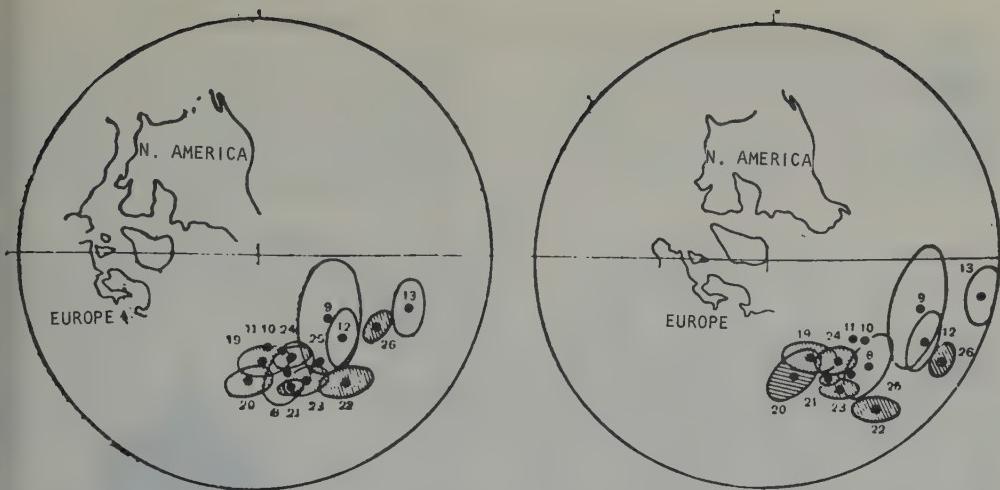


FIGURE 10. Two reconstructions of the relative positions of North America and Western Europe (left: after Carey; right: after A. Du Toit) in pre-Jurassic times, as compared with the data on paleomagnetism

Positions of the poles as reconstructed and curves of reliability around them, based on the rocks of Western Europe (unhatched; figures indicating the ages of the rocks: 8 - Triassic; 9 - Permian; 10 and 11 - Carboniferous; 12 - Devonian; 13 - Cambrian) and of the U.S.A. (hatched; 19 and 20 - Triassic; 21 and 22 and 23 - Permian; 24 and 25 - Carboniferous; 26 - Silurian). After E. Irving. It will be seen that S. Carey's reconstruction produces a more complete coincidence of the positions of the poles in the individual geologic periods, as determined by the paleomagnetism of the rocks of North America and Europe.

G. Stille, L. Coberg, J. Gregory) and by the nobilist school. A. Heim, J. Oden, D. Vadia, and Krishnan noted the nappe-like structure of the Himalayas and stressed the active role of a northerly to northeasterly movement of Hindustan. "Hindustan Peninsula must have moved north (or northeast, since this movement is normal to the general trend of the Himalayan arc), over a considerable distance... The several phases of the Himalayan uplift may be regarded as active stages of this drift and the edging up of India within the Thetis province" [11], pp. 55, 199).

Geophysicists E. Glenny, G. Jeffries, and others cited data on the horizontal movements of Hindustan in order to explain the almost two-fold thickening of the crust underneath the Himalayas and Hindu Kush. Judging from the range of the high peneplains, the huge "root of the mountains" was formed in close association with folding and with the piling up of major thrusts and nappes.

Naturally, the scope of this shift has been subject to different interpretations. E. Argan believed that the rapprochement of India and the Tarym massif in Central Asia had been on the order of 2000 km. "Other deductions, cited by Wegener, bring this figure up to about 3000 km, or the northeasterly shift of India, alone" ([2], p. 153). The same figure is given by R. Schaub and E. Kraus [27, 49].

As we have seen, paleomagnetic data suggest this very magnitude of the shift. E. Argan's reconstruction of the Middle Mesozoic Gondwanaland (Figure 11) coincides with later reconstructions by R. Maack (Figure 7) and is in better agreement with geologic and paleomagnetic data than reconstructions by A. Du Toit and L. King. More specifically, it fits in with paleomagnetic data for the Madagascar Cretaceous rocks, which may be interpreted to suggest a northeasterly movement of that island, in the formation of Mozambique Strait [54]. In E. Argan's reconstruction, the South Polar coordinates fall at the Antarctic coast on the basis of data from South America, Africa, Hindustan, and Australia, as computed from Jurassic rocks or as an average for the Triassic, Jurassic, and Lower Cretaceous. Individual determinations are so close to each other that their divergence may be ascribed to errors. A similar result was obtained by E. Irving in his reconstruction of the Gondwanaland, after A. Du Toit ([12], Figure 7). Without such reconstructions, the position of the pole, determined from contemporaneous rocks from different parts of Gondwanaland, is not determinable.

Ever since the Suess days, the structure of island arcs has been regarded usually as the result of their uneven oceanward progress. In such a movement, segments of an arc rotated somewhat relative to one another. It is believed, for example, that the south segment of the Japanese arc (Island of Kyushu and half of



FIGURE 11. A reconstruction of the continent of Gondwanaland during the period preceding its dismemberment (after E. Argan) and the position of the South Pole, determined by the paleomagnetism of the Jurassic rocks of India and Australia or as an average interpolated from the paleomagnetism of the Triassic, Jurassic and Cretaceous rocks of Africa and South America

1 - sima; 2 - sial, with a predominance of anticlinal folding at depth; 3 and 4 - crests and plunges of the axes of the deep folds; 5 - lines connecting objects now separated; 6 - projections of Jurassic and Middle Mesozoic poles based on the paleomagnetism of the rocks of India, Australia, Africa and South America in Argan's reconstruction. Exposures of Gondwanaland within the Tethys zone: a - African, b - Arabian, c - Indian

Honshu) was rotated clockwise, while bending, with relation to its northern segment and the continent of Asia. In the works of T. Kobayasy, the structure of Japan and of the Japanese Sea trough is regarded as the result of a break and separation, bending, and drift of the Japanese arc, over a distance of 450 km to the east. This conclusion, based on a similarity in sections within structures of the same type, in Japan, the Maritime Province, and Korea, was supported by S. N. Bubnoff [31] and is corroborated by most recent geologic and bathymetric data. In reconstructions of Chinese tectonists

([13], pp. 264-288), mobility of the continents is marshaled up to explain structural features of the Chinese Platform which present distinct evidence of various horizontal movements (lateral, folding, thrust).

Paleomagnetic data on the upper Mesozoic and Cenozoic of central and southwestern Japan are in agreement with the concept of a rotation of the southern segment of this arc [53]; paleomagnetism of Silurian rocks in China indicates, according to Chang Wen-yu and A. Nairn, a considerable shift with relation to Europe [34].

VI. CONCLUSIONS

A review of data on paleomagnetism shows that this interesting phenomenon may contribute such new material to stratigraphy, lithology and geotectonics. The feasibility of applying the paleomagnetic method to geochronologic correlation of sections appears to be established.

Paleomagnetic data suggesting large horizontal crustal movements should be evaluated in the light of recent geologic and geophysical data on lateral faults and other tangential movements. Thus, a detailed study of petrotectonics in folded structures (G. D. Azhgirey, E. Cloos) suggests a considerable lateral compression of individual folds and entire folded systems, produced by tangential stresses.

The total contraction across the strike, for group of thrust scales in the central Rockies is estimated to be 130 km in most recent works. The magnitude of thrusts has been determined to be 107 km for Scotland, 256 km for the north-eastern Pacific (from the displacement of magnetic anomaly zones crossed by the Pioneer fault); and, less certainly, 370 to 480 km, for strike-slip faults of California and New Zealand. Considerable stretching must be postulated in order to explain that the thickness of the crust, from the surface of the folded basement (i. e., the base of the sedimentary mantle) down to the Mohorovičić discontinuity is considerably less in major downwarps than in places of no subsidence. A further expression of the same process appears to be represented by grabens and troughs of the Red Sea, Gulf of Aden, Mozambique and Baffin Straits, the Black and Japanese Seas, and the Atlantic and Pacific. In these features, judging from geophysical data, the crust thins down until the granite layer is almost completely wedged out. In all these examples, both the isostasy and seismic data support the concept of major faults in the continental crust and the drifting of segments great distances away from each other.

One cannot pass over the fact that mobility has been accepted in the works of outstanding geologists who have studied the North Atlantic margin directly, (W. Holtedahl, S. Bubnoff, and others) or the Gondwana structure (A. Du Toit, L. King, and M. Robert, in Africa; R. Maack, G. Ebert, G. Hert, D. Guimaraes, and O. Leonardos, in South America; and the Indian geologists M. Krishnan, Ch. Fox, etc.). As demonstrated by M. Gignoux, K. Beurlen, D. Guimaraes, and L. King, a general synthesis of paleogeography and stratigraphy of Gondwanaland is impossible without mobilist reconstructions [8, 30, 41, 47].

The last stages of the disintegration of Gondwanaland were traced by F. Walker, A. Poldervaart, and L. King from the distribution of freshwater Lower Cretaceous sediments and

from the penetration of a transgression occurring in the Late Cretaceous, along the grabens, preceding the final separation [21, 40, 46]. By means of special stereographic projections, S. Carey has shown recently the excellent coincidence in the continental slope outlines for Africa and South America, as reconstructed after Wegener [33].

M. V. Muratov notes that despite the similarity in the structure on either side of the Atlantic, geophysical data and relief "lead to the conclusion that there are no submerged continental massifs at the bottom of the Atlantic, although this ocean is located between such blocks. Only two explanations can be advanced for the paradox of the radical difference in the Atlantic and the adjacent continental crusts: 1) a shift in blocks of the continental crust over the underlying mantle, i. e., a separation of the continents as postulated by the Wegener hypothesis; or 2) the submerged continental crustal segments have been dissolved or, more properly, melted away almost without a trace" ([15], p. 61).

Inasmuch as the second alternative is unacceptable on physico-chemical and geophysical grounds, as demonstrated by G. Ramberg, M. Bott, Ye. N. Lustich, and V. A. Magnitskiy, mobility has the field. In the current theories of epeirogenesis, widely accepted abroad, movement of continental blocks and the deformation of beds into geosynclines is usually associated with the action of subcrustal currents in the mantle. These deep-seated currents drag along crustal blocks that are only passively involved [6, 22, 39, 48, 49]. Zones of deep-focus earthquakes in geosynclines fringing the Pacific are regarded as the manifestation of a descending branch of these deep-seated currents. This variation of "neomobility" does away with N. S. Shatskiy's objections to the Wegener theory [25].

S. Bubnoff and A. Du Toit have demonstrated convincingly that the Mesozoic and Cenozoic movements were essentially a flow of material from two provinces, Gondwanaland and Lawrasia (including North America and northern Eurasia), in the direction of newly-forming young folded chains, i. e., toward the Thetis and the Pacific [31, 38]. It is possible that a third such province of extension lies in the Pacific basin. "In any event, a shifting of blocks toward the Mediterranean zone and toward the Pacific is more than probable" ([32], p. 65). In Bubnoff's opinion, the contraction theory does not explain the geometric and temporal geotectonic regularities. He states, "It seems to me that there is no way out of this situation, other than to assume the presence of thermal subcrustal currents, as postulated by A. Holmes, D. Griggs, F. Weping-Meynes, and more recently by Gavemann, and after this source of stress has been suggested by Ampherer, Schwinner, and Kraus" ([4], p. 228).

Thus the most recent geophysical data, seismic sounding, gravimetry, and magnetic surveying, which have demonstrated the absence of submerged "intermediate" continents in the oceans, taken in conjunction with paleomagnetism, force a revision of earlier geotectonic concepts and indicate the presence of major horizontal movements of crustal and subcrustal masses.

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Received, 21 July 1960

NEW DATA ON THE STRATIGRAPHY OF THE RIPHAEAN GROUP (UPPER PROTEROZOIC)¹

by

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A general stratigraphic subdivision of the Riphaean group, applicable over extensive areas of the world, may be made only with the aid of some method yielding objective data for the correlation of sections. Many hopes in this respect had been placed in the method of spore-pollen analysis. But in recent years it has been found that there are extensive rewashings of the spores, and that they are washed downward to great depths from above through fractures in the rocks [32]. This circumstance, along with the very scanty spore assemblages in the Riphaean and the lack of any reliable criteria for distinguishing reashed or down-washed spores from spores occurring in their original location, have essentially excluded, at the present level of knowledge, any use of spore-pollen analysis for the correlation of Precambrian deposits. For this reason we have attempted to find another method, making use of data on absolute ages along with the study of stromatolites.

This article presents the results of investigations made over many years by B. M. Keller, and I. N. Krylov in the Urals, by M. A. Semikhatov on the Yenisey Ridge and by S. V. Nuzhnov in the Uchur-Maya region. The data on the absolute ages of the rocks are presented by G. A. Kazakov, and the materials on the stromatolites and their morphological features by I. N. Krylov, S. V. Nuzhnov, and M. A. Semikhatov. B. M. Keller directed the general preparation of this paper.

THE METHOD USED FOR DETERMINING THE ABSOLUTE AGE OF THE ROCKS

Until recently, all the determinations of absolute age were made on the minerals in intrusive rocks. Nevertheless there are few places known in nature at which the relative age of the intrusives and their derivatives, with respect to the surrounding and underlying

paleontologically characterized strata, may be determined within narrow limits.

In the U. S. S. R. at the end of the 1940's, E. K. Gerling [5] suggested the use of the potassium argon method for absolute geochronology; this has considerably expanded the possibility of determining absolute age.

The first determinations of absolute age by this method were made by analyzing the minerals of igneous rocks (potassium felspars, micas); among the sedimentary minerals only sylvite, which is of limited distribution, was used.

Since the middle 1950's a number of investigators [10, 28, 33, 34] in determining absolute age have made use of the potassium-containing silicate of iron — glauconite — which is an authigenic mineral occurring widely in marine sedimentary deposits of various ages. Thus it has become possible to determine the absolute ages of sedimentary rocks directly, without recourse to indirect means of dating them by the ages of one intrusive or another.

Glauconite, as a number of investigators [5, 10, 32, 33, etc.] have stated, retains its radiogenic argon (Ar^{40}) quite well, regardless of its geologic age. The cationic exchange of potassium in it is not great, on the average amounting to 5% of the content of this element in the mineral. A correction for the sorbed potassium may be introduced into the computation of the absolute age. From the color of the glauconite one can reliably decide whether the given variety is suitable for study. If the glauconite is brown under the microscope, it has undergone secondary processes such as weathering and metamorphism, and in this case cannot be used for absolute geochronology, since there may have been considerable losses of radiogenic argon and potassium. Only the green varieties are suited for determination of the absolute age.

Comparison of the figures for absolute ages as obtained from glauconites and from the minerals in igneous rocks shows close agreement.

¹ Novyye dannyye po stratigrafii rifeyskoy gruppy verkhniy proterozoy.

The effect of metamorphism on micas and potassium felspars in igneous rocks is detected only with difficulty (and sometimes cannot be detected at all). In thin sections or separated fractions it is hard to distinguish the metamorphosed biotite or potassium felspar from the unaltered magmatogenic minerals; both will look alike when studied by optical methods, although they will have been formed (or altered) at different times, so that the figures for the age of the rock will in one case reflect the time of their primary formation, and in the other the time of the later metamorphism of the rock.

Error in any method of determining absolute age may be due to a number of physiochemical, mineralogical and geological causes, which must be taken into account in making such an investigation. In this case the error in the potassium-argon method is the result of insufficient accuracy in determining: 1) the constants for α -decay of K^{40} and K-capture; 2) the amount of potassium and argon; 3) the mass-spectrum analysis of the isotope composition of the argon; 4) the degree of preservation of the mineral; and 5) even the treatment of the rock in removing the monomineralic glauconite fraction.

A. P. Vinogradov [1] estimates the error in the potassium-argon method to be, on the average, $\pm 5\%$. With the increasing age of the glauconite, the absolute error increases but the relative error decreases. For example, in the case of Cretaceous rocks, their absolute age being 100 million years, the error in the determination amounts to $\pm 5\%$ (95 - 105 million), or ten per cent, whereas in the case of a rock 1000 million years old the greatest deviation will be 50 million years (975 - 1025 million), or 5%. In the case of young, Mesozoic and Cenozoic, rocks this error can have no great effect on correlations based on absolute age determinations. It is another matter with Precambrian series, however, where the error of the method may be very great in absolute magnitude, and must be taken into account in drawing geologic conclusions.

The distortion of the figures for the absolute age that is caused by secondary processes is no less considerable. If the radiological error is in the same direction as the error produced by the secondary alteration of the rock, the sum of the two will yield clearly unreliable figures. Hence the figures for the absolute age, in cases where they stand alone and are not confirmed by other determinations from the same and from the overlying and underlying formations, must be considered as preliminary. When there are a number of closely coinciding determinations from a single point, along with a series of successive reliable determinations throughout the section, the figures may be taken as confirmed.

THE METHODS OF STUDYING STROMATOLITES FOR THE CORRELATION OF SECTIONS

Stromatolites are layered, calcareous crusts of various forms, attached to the substrate and formed over a long period of time by the biological activity of algae and, possibly, of bacteria [23, 24]. Stromatolites are widespread in deposits ranging from early Precambrian to modern; they are very complex formations consisting of extremely thin (from fractions of a millimeter to several millimeters) layers or lamellae corresponding to the seasonal growth of the algal colonies, whose algae were capable of secreting calcium carbonate during their life processes as mucous masses around the cells and fibres.

The separation of lime by the algae is often combined with another process — precipitation of the carbonate and more rarely terrigenous material settling in the basin. The result of numerous repetitions (over many years) of this activity is the appearance of the stromatolitic structures, whose morphology is evidently determined by: 1) the species and genera of the algal colonies; 2) the conditions of illumination; 3) the relationship between the rate of growth of the colonies and the rate of sedimentation, the directions and strength of the currents, the oscillations of the water caused by waves, etc.

The first attempts to use stromatolites in the stratigraphic subdivision of ancient formations were made more than 50 years ago, but these attempts, like many later ones, were unfortunately not successful. Inaccuracies in the identification of stromatolites and errors in determining the ages of deposits on this basis gave rise to the widely held opinion that stromatolites were unsuited for stratigraphic purposes. It should be noted, however, that the mistaken identifications and the erroneous age determinations were made in the early stages in the study of stromatolites, and were to a considerable degree caused by the insufficiency of materials that could be compared and to the limited study of the successive stratification of the surrounding deposits. At the present time, as a result of detailed study of the stratigraphy of the Precambrian sedimentary rocks and the acquisition and treatment of a large amount of new data on stromatolites whose positions in the section cannot be questioned, it is appropriate to reconsider the problem of the stratigraphic significance of stromatolitic bodies.

In recent years there have been three main tendencies in the study of stromatolites. The first is closely associated with the earlier stages in this study [Walcott, the Fentons, V. P. Maslov — 20, 21, 22, etc.]; this is concerned with the determination, in longitudinal and transverse sections, of the general form and

nature of the layered structures. Outside the Soviet Union these methods have been used by L. Rezhak in the U.S.A., N. N. Men'shikov in France and other investigators. Along these lines, I. N. Krylov [18] has suggested a method of accurately reconstructing the outward form of the stromatolite: the specimen is cut into thin parallel plates, and the form is established in these by means of block diagrams. The chief morphological criteria are the general form of the structure, the type of branching, the nature of the wall surfaces, as well as the type of layering of the unit microlayers and the way in which the surfaces of the stems are surrounded by them.

The second tendency, which has been developed by A. G. Vologdin [2, 3] and K. B. Korde [14], is based on microscopic study of the remains of stromatolite-forming algae. This trend may prove to be the soundest, from the biological standpoint, as well as the most promising. On the other hand, at the present time it is impossible to use this method for stratigraphic correlation, because of the extremely poor state of preservation of the microscopic algal remains and the insufficient study that has been devoted to them.

The third tendency, represented by I. K. Korolyuk [15, 16], is based, while taking account of the general form of the structure, on study of the morphology and structure of the lamellae or layers and the nature of the lining formed by them on the surfaces of "walls" of the structures.

At the Institute of Geology of the U.S.S.R. Academy of Sciences, where there is a rather large collection of stromatolites from the Riphaean deposits of the Urals, the Yenisey Ridge, the Turukhan uplift and the Uchur-Maya area, I. N. Krylov [17, 19], S. V. Nuzhnov [26] and M. A. Semikhato [30] have successively used all the methods described here. In the course of their work it was established that the following basic aspects of stromatolitic structures may be used for stratigraphic subdivision of Precambrian sedimentary strata: the type of wall surface, the nature and structure of the lamellae and the general form of the structure created by them, and the nature of its branching.

On the basis of the material that has been worked over, there is full justification for distinguishing a large number of groups of late Precambrian stromatolites, but for the sake of simplicity in this article only the well-known division of the stromatolites into two major groups — Collenia and Conophyton — has been used.

Below we shall present a brief description of the Riphaean sections that have been studied, a necessary basis for a proper understanding

of the distribution of stromatolites and of rocks whose absolute ages have been determined.

THE RIPHAEAN GROUP (UPPER PROTEROZOIC) OF THE SOUTHERN URALS

The stratigraphy of the Southern Urals Riphaean group has been treated in papers by M. I. Garan' [4], O. P. Goryanova, and E. A. Fal'kova [6], N. S. Shatskiy [31], A. I. Olli [27], B. M. Keller [11] and others. All these authors have stated that these sedimentary rocks, some 15,000 m or more thick, may be subdivided into three major series which overlie each other with gaps and unconformities, each of them beginning with clastic and ending with carbonate formations. A general section through these deposits may be presented as follows:

The Burzyantsy series overlies the gneisses of the Tarataш suite with a gap and an angular conformity.

The Ay formation consists of tuffaceous conglomeratic sandstones interlayered with basic extrusives and their tuffs; toward the top are quartz and arkosic sandstones and carbonaceous slates. The thickness is about 1500 m.

The Satka formation is made up of gray and dark gray dolomites with packets of phyllitic slates. Peculiar conophytons and layered stromatolites of the type of Stratifera Koroljuk and Collenia kusiensis Maslov are encountered [17, 19]. The thickness is 2400 m.

The Bakal' formation contains sericitic and quartz slates with packets of dolomites and dolomitized limestones. There are stoloniferous-nodular stromatolites of the types Collenia symmetrica Walcott, C. Columnaris Fenton et Fenton and Conophyton cylindricus Masl. The thickness is 1200 m.

The Yurmatintsy series follows the underlying formations, with a gap.

The Zigel'ga formation consists of quartzites and quartzitic sandstones, containing packets of slates and siltstones in the upper part. The thickness is from 500 to 1500 m.

The Zigazino-Komarovsk formation is made up of sandstones, siltstones and shales, with a thickness up to 1400 m.

The Avzyan formation contains dolomites and dolomitized limestones with packets of sandstones, siltstones and carbonaceous shales. At the top is a packet of light gray and cinnamon-brown dolomites with lenses of chert. There are stromatolites of the types Stratifera Korol.,

Collenia columnaris Fent. et Fent., C. bai-
calica Masl., C. frequens Walc. and Conophyton
lituus Masl. The total thickness is 1200 - 1400
 m.

The Karatavskaya series follows next in the section, after an erosional gap that cuts the upper packet of the Avzyan formation.

The Zil'merdak formation consists of reddish brown and light-colored arkosic quartzitic sandstones with packets of siltstones. The thickness is 1400 - 2300 m.

The Katav formation is made up of plicated fine-grained multicolored limestones and marls, sometimes showing a characteristic "lenticular" bedding. The thickness is 250 - 300 m.

The Simskaya (Podynzerskaya) formation of light-colored bedded dolomites contains stromatolites of the types Collenia ferrata (?) Grout et Broderick and C. ramsayi Steinmann. The thickness is 100 to 150 m.

The Min'yarskaya formation consists of various dolomitized limestones and dolomites with chert. Collenia burriatica Masl. is universally encountered. The thickness is 200 - 700 m.

The Min'yarskaya formation of the Karatav series is overlain by the Ashinskaya series, which is composed primarily of clastic rocks (siltstones and sandstones), including a resistant layer of conglomerates in the middle. According to Yu. R. Bekker the Ashinskaya suite overlies the formations beneath with a stratigraphic gap, and is transgressively covered by rocks of the Devonian, Silurian and Upper Ordovician. In recent years the majority of geologists are inclined to believe that the Ashinskaya suite is of the same age as the Valday series of the Russian platform. Some investigators include both these subdivision within the Late Precambrian, whereas others place them at the bottom of the Cambrian system. The latter opinion is based on spore-pollen data.

In the case of the Riphaean formations of the Southern Urals which contain syngenetic glauconite, a number of figures for the absolute ages of various rocks have been obtained [for the Avzyanskaya formation 1260 million years, for the Inzerskaya formation 880 - 920 million years, for the lower part of the Min'yarskaya formation 760 million years, for its upper part — the Uksaya formation — 616 million years, and for the Ashinskaya suite 570 million years; 10, 28, 29]. These figures are regularly distributed through the stratigraphic section and strongly suggest two suppositions: 1) the slow deposition of the sedimentary formations in the Riphaean era, and 2) the very great age of the Lower Riphaean, which is probably all older

than 1200 - 1400 million years and may possibly correspond to some part of the Proterozoic section of the Baltic Shield (for example, the Iotnian, which is older than 1400 million years). There are still not enough data for a conclusive answer to these two questions.

On the basis of stromatolites and absolute age figures, the Riphaean formations indentified on the Russian platform and its adjoining basins may be correlated with the Urals type section. Here it appears that the analogues of the Yurmatinskaya series exist only in the easternmost part of the platform, where, on the basis of absolute age data (1290 million years), they may be correlated with the Serafimovskaya formation [28]. In the remainder of the platform, transgressively overlying the crystalline basement rocks, are deposits of the same age as the Upper Riphaean (the Kaverinskaya and Serdobskaya formations of the Pachelmsky depression, whose ages are 940 and 970 million years respectively). Of particular interest is the coincidence in the date of the Kil'dinskaya series of the Murmansk area, which is 1000 million years old [28] and contains Collenia ramsayi Steinm. [17]. In the Urals this fossil form is found in the Podynzerskaya formation, below the Inzerskiye sandstones, which are 920 million years old.

THE RIPHAEAN GROUP (UPPER PROTEROZOIC) OF THE TURUKHAN REGION AND THE YENISEY RIDGE

East of the Urals there are extensive outcrops of the Riphaean in the Turukhan region and the Yenisey Ridge. These deposits have been studied by A. K. Meyster, S. V. Obruchev, A. G. Vologdin, A. I. Gusev, G. I. Kirichenko, F. G. Markov, Yu. A. Kuznetsov, A. A. Predtechenskiy, and more recently by G. I. Kirichenko [12, 13], A. V. Lesgaft, F. Ya. Pan, A. K. Rublev, V. L. Fisher, V. I. Dragunov [7], M. A. Semikhatalov and others; the description that follows is based on their data.

The most complete section through the Riphaean in this zone occurs in the central and southern parts of the Yenisey Ridge, consisting (from bottom to top) of:

The Teyskaya series, which is exposed in the axial zone of the Yenisey Ridge metanclinorium, and is intersected by numerous granitic intrusives and is usually highly metamorphosed.

The Karpinskiy Range formation consists mainly of crystalline schists and gneisses; its thickness is more than 1000 m.

The Penchenga formation is made up of marbles, often amphibolitized, with interlayers of hornstones, quartzites and schists. The

thickness is 1200 - 1500 m. The Teyskaya series is commonly assigned to the Lower Proterozoic, chiefly on the basis of its high degree of metamorphism and of unconfirmed indications of the unconformable occurrence of the overlying formations above it. This view must now be abandoned, since these formations, as will be seen below, may be correlated with the lower strata of the standard section through the Riphaean in the Gornaya Bashkiriya region.

The Sukhopitskaya series conformably overlies the Teyskaya series.

The Borbilok formation consists of phyllitized argillaceous-chloritic greenish-gray slates and phyllites, to a thickness of 800 m.

The Uderey formation contains dark argillaceous and silty-argillaceous phyllitic slates; its thickness is 1000 - 1500 m.

The Pogoryuy formation, of dark sandy-argillaceous slates, sandy phyllitic slates with layers and packets of quartzitic sandstones and siltstones, is up to 1500 m thick. The absolute age of these rocks, according to potassium-argon determinations, is 1140 million years. In the axial zone of the Yenisey Ridge metanticlinorium the latter three formations do not differ in places from the Teyskaya series in their degree of metamorphism, and are represented by crystalline schists, gneisses and gneissose quartzites.

The Kartochka formation is the most important Riphaean index stratum in the Yenisey Ridge and the Turukhan region: it consists of banded, thin-bedded limestones and marls. Its thickness is 200 - 500 m.

The Alad'yinskaya formation is made up of gray dolomites, in places containing magnesite, 150 - 600 m thick.

The Tungusik series overlies these conformably, in places with an erosional gap. This consists of:

The Krasnaya Gorka formation, composed of black, gray and pinkish clay shales, frequently containing chloritoid and interbeds of siltstones and sandstones. The thickness ranges from 100 to 1000 m.

The Dzhur formation consists of gray and pinkish-gray, usually stromatolitic dolomites and limestones, with interbeds and packets of clay shales. Among the stromatolites of this formation the most widely occurring are conophytes of the group Conophyton lituus Masl. and the closely related Collenia frequens Walc.; Collenia baicalica Masl. is sometimes encountered. The thickness is 200 - 800 m.

The Shuntarskaya formation is made up of

black argillaceous and carbonaceous-argillaceous shales, with interbeds of siltstones, limestones and dolomites which often contain stromatolites. The thickness is 800 - 1200 m.

The Seryy Klyuch formation consists of thin-bedded, dark gray limestones and sometimes marls, in places containing stromatolites in the uppermost 100 m. The total thickness is 400 - 800 m.

The Dadykta formation contains dark clay shales with interbeds of sandstones, and sometimes also stromatolitic dolomites. The thickness is 500 - 600 m.

The Oslyanka series lies with an erosional gap upon the Tungusik series.

The Nizhnyaya Angara formation consists of clay shales with interbeds of quartzites, in the lower part containing usually hematitic quartzites and frequently hematite ores. The thickness is 400 - 600 m.

The Dashka formation consists of thin-plated black limestones and dolomites (in part stromatolitic), with a thickness up to 2500 m.

The formations described above are unconformably overlain by red and light-colored sandstones, conglomerates, argillites and their subordinate dolomites of the Koval' (Lopatin-skaya), Aleshinskaya (Chividinskaya) and Shalyginskaya (Nemchanskaya) formations. The latter formations are gradually replaced upward in the section by a thick carbonate series (the Lebyazh'ya formation in the north and the Klimino and Agaleva formations in the south), within which a number of strata of the Lower Cambrian Lena stage may be distinguished on the basis of the trilobite remains.

There are no paleontological data on the ages of the Koval', Aleshinskaya and Shalygin-skaya formations. In view of the fact that they unconformably overlie the Upper Riphaean and gradually merge upward into the paleontologically characterized deposits of the Lena stage, it may be tentatively said that they belong to the Aldan formation. This conclusion, if true, is contradicted by the single figure that has been obtained for the absolute age of the Chividinskaya formation - 740 million years. But this contradiction is considerably mitigated by the fact that the age of the Yerkeket formation on the Olenek uplift, which on the basis of its fauna belongs to the upper half of the Aldanian stage, has been determined as 760 million years. Thus it appears that both of these figures require greater precision and correction.

The Turukhan region: here the analogues of the middle and upper parts of the section just described are exposed.

At the base of the section exposed in the Turukhan region lie the Bezymenskaya (visible thickness 800 m) and Litok (thickness about 200 m) formations, which differ from the Pogoryuy and Kartochki formations only in the details of their composition and structure. Higher in the Turukhan section these are followed conformably by the:

Sukhaya Tungusska formation, the lower part of which is represented by dark-colored limestones with stromatolites at its very top (about 200 m thick), and in the middle by dolomites with chert lenses and interbeds (300 - 390 m). Among the stromatolites, columnar wall-less structures of the group Collenia baicalica Masl. predominate. This formation is correlated with the Alad'yinaya and Krasnaya Gorka formations of the Yenisey Ridge.

The Derevnya formation: this consists of stromatolitic dolomites and dolomitized limestones with an eighty-meter thick packet of quartzites and multicolored clay shales in the center. In these shales V. I. Dragunov [8] has found remains of Sabellidites ex gr. cambriensis Jan. Among the stromatolites of the Derevnya formation the most common are Conophyton litus Masl. and Collenia frequens Walc., and stromatolites of the Collenia baicalica Masl. group occur less numerously. This formation, in its lithologic composition, its stratigraphic position and, as G. I. Kirichenko [12] has stressed, in the composition of its stromatolites, correlates perfectly with the Dzhur formation of the Yenisey Ridge.

No direct analogy has yet been observed in the successive stratification of the overlying Riphaean deposits as between the Turukhansk region and the Yenisey Ridge.

The Burovoy formation: the lower part consists of dark-colored brecciated dolomites containing a packet of stromatolitic pinkish-gray dolomites, followed above by dolomites that contain interlayers of clay shales, brecciated and stromatolitic dolomites. At the top of this formation, along the Nizhnyaya Tungusska River, below the Strel'nyye Mountains, there is a small packet of clay shales and glauconite-quartz sandstones with a siderite cement. According to the determinations made by the potassium-argon method, the absolute age of these rocks is 925 million years [28]. The stromatolites are represented by columnar, wall-less, frequently very large forms of the Collenia baicalica Masl. group. The thickness of this formation is 900 - 1000 m; it is correlated with the Shuntarskaya formation of the Yenisey Ridge.

The Shorikhinskaya formation consists of light-colored, mainly stromatolitic dolomites, with lenses of chert in the upper part. Among the stromatolites, along with the wall-less

forms of the Collenia baicalica Masl. group, there are also columnar stromatolites of the Collenia buriatica Masl. and C. ramsayi Steinm. groups, whose unit layers surround the lateral surfaces of a column, thus forming a "wall". The thickness is 600 - 700 m. The Shorikhinskaya formation is correlated with the Serry Klyuch formation and the Dadykta sub-formation of the Yenisey Ridge.

The Miroyedikha formation consists of greenish-gray and red argillaceous limestones and dolomites, with a packet of multicolored clay shales at the bottom. The thickness is 200 m.

This is overlain by a 700 - 800 meter series of highly stromatolitic dolomites, the lower and red-colored part of which has been distinguished in the Turukhansk formation, the middle dark-colored part in the Rechka formation and the upper part, where there is a predominance of brownish- and yellowish-gray shades, in the Durnaya Mys formation. Among the stromatolites of this formation, the most commonly occurring are forms of the Collenia buriatica Masl. group. The Miroyedikha, Turukhan, Rechka and Durnaya Mys formations are correlated with the Oslyanka series in the Yenisey Ridge.

The formations just described are overlain, with a deep erosional gap and sometimes an angular unconformity, by Cambrian deposits, which are represented by the terrigenous-carbonate rocks of the Aldan formation and the carbonate rocks of the Kostino formation, somewhere below the middle of which are trilobites of the Olekma stratum in the Lena stage.

THE RIPHAEAN GROUP (UPPER PROTEROZOIC) OF THE UCHUR-MAYA REGION

The Uchur-Maya region encompasses the southeastern margin of the Siberian platform and the surrounding folded structures of the Yudoma-Maya miogeosyncline and the geanticlinal uplifts of the Stanovoy and Dzhugdzher Ranges. The stratigraphy of the Riphaean in this region has been studied by V. A. Yarmolyuk, Yu. K. Dzeyanovskiy and others; the most widely accepted stratigraphic scheme in carrying out geologic mapping operations has been that of V. A. Yarmolyuk, supplemented by S. V. Nuzhnov [25]; the following description will also be based on these materials.

The Uyan series lies with an angular unconformity upon the Archean and Lower Proterozoic rocks of the crystalline basement. One formation — the Konkulinskaya — has been recognized; this is represented by red arkosic and quartz-felspathic sandstones with interbeds

of conglomerates and siltstones. The thickness is 0 - 400 m in the platform part of the region and up to 1000 m in the miogeosyncline.

The Uchur series lies with a stratigraphic unconformity upon the Uyan series and the quartz porphyries and alkalic granites of the Ulkan subvolcanic complex which intrude it; in places the Uchur series lies directly upon the crystalline basement.

The Conam formation is made up of red and gray arkosic and quartz sandstones with layers of stromatolitic dolomites, dolomitic limestones, siltstones and, in some places at the base, also conglomerates. The carbonate rocks have been found to contain layered and columnar-layered stromatolites; among the latter the typical structures are those of the type *Collenia kusiensis* Masl. The age, according to the glauconites from a sample of the stromatolitic dolomites, is 1500 million years. The thickness is 200 - 600 m in the platform part, and 1500 - 2000 m in the miogeosyncline.

The Okhmatinskaya formation consists of gray dolomites and dolomitic limestones which are frequently siliceous, with layers of argillites, siltstones and sandstones. The carbonate rocks contain an abundance of layered and layered-columnar stromatolites of the *Collenia kusiensis* type, and more rarely structures of the *Conophyton* group. The thickness on the platform is no more than 500 m, but reaches 1000 - 1300 m in the miogeosyncline.

The Maya series on the eastern slopes of the Aldan shield is separated by an erosional gap and a stratigraphic unconformity from the rocks of the Uyan and Uchur series; in the Yudomo-Mayo miogeosyncline it overlies the latter conformably, without any hiatus.

The Yenninskaya formation consists of gray quartz sandstones interlayered with yellowish-brown and greenish-gray siltstones, and in places with dolomites and dolomitic limestones that contain layered and columnar-layered stromatolites of the *Collenia kusiensis* Masl. type, along with rare specimens of *C. baicalica* Masl. According to determinations from the glauconites in the sandstones, the formation is 1200 million years old. At its base is a layer of gravelite and conglomerate that dies out laterally. The thickness varies from 100 to 600 m.

The Omninskaya formation is made up of thin-bedded greenish-gray and cinnamon-brown siltstones and argillites with thin interbeds of hematitic and sideritic siliceous rocks at the top. The thickness ranges from 200 to 800 m.

The Malginskaya formation consists of thin-bedded varicolored pelitomorphic and argilaceous limestones, at the top of which, in the

center of the Maya River basin, there is a ten-to thirty-meter stratum of black combustible shales and bituminous limestones. According to V. A. Yarmolyuk, this formation in places contains columnar stromatolitic structures. The thickness varies from 50 m on the platform to 400 m in the miogeosyncline.

The Tcipandinskaya formation in the central part of the Uchur-Mayo block is separated by a hiatus from the rocks of the Malginskaya formation, whereas in the other areas it merges gradually and directly into them. The formation is composed of massive light-colored dolomites which in places contain columnar and laminar stromatolites. Among the latter, the most common are structures closely resembling *Collenia baicalica* Masl. The thickness is 250 - 500 m.

The Lakhandinskaya formation presents an alternation of packets of stromatolitic limestones and dolomites with packets of predominantly siltstone and argillite composition, which are most abundant in the platform part of the region. The formation has a great abundance of stromatolites, among which the common types are *Conophyton lituus* Masl. and stemless columnar structures of the *Collenia baicalica* Masl. type. The thickness ranges from 300 to 1200 m.

The Uya series conformably overlies the rocks of the Maya series; it is separated by a hiatus only in the westernmost outcrops.

The Kandyk formation consists of white, gray and more rarely reddish quartz sandstones with interbeds and packets of cinnamon-brown siltstones and isolated layers of limestones. In Yudomo-Mayo miogeosyncline the most abundant rocks in the composition of the Kandyk formation are platy fine-grained sandstones and siltstones of gray and brownish-gray color. The thickness varies from 300 to 1500 m.

The Ust'kirbiinskaya formation occurs only within the Yudomo-Mayo miogeosyncline; it is represented by brownish- and greenish-gray siltstones and argillites, the middle and upper parts of the section in places containing dirty green polymictic sandstones and occasional gravelites, and the lower beds containing red sandstones and siltstones. The thickness ranges from 150 - 300 m to 3000 m (in the Ulakan-Bam range).

The Kurunuryakh formation is separated by a regional stratigraphic unconformity, and in a number of places also by an angular unconformity, from the underlying deposits of the Uchur, Mayo and Uya series. Its total thickness is more than 3000 m, represented by alternating thick packets of gray and white dolomites, varicolored and gray siltstones, argillites, sandstones and limestones. The latter often contain stromatolites, among which the most commonly

occurring are structures of the Collenia ramsayi Steinm. type.

Upon all the above-described deposits, both in the west, in the basin of the left tributaries of the Uchur River, and upon the Archean rocks, are the transgressively overlying dolomites and dolomitic limestones of the Yudomskaya formation, which contain a basal stratum of quartz sandstones and gravelites in the form of lenses and interlayers. Upward in the section these are gradually replaced by the limestones of the varicolored formation, containing the remains of fauna of the Zhurinskaya substage of the Lower Cambrian Aldanian stage. The interruption in deposition that separates the Yudomskaya formation from the Riphaean deposits was accompanied by the injection of a peculiar complex of alkaline intrusives of the central type (the Ingiliyskiy massif and others), whose absolute age has been determined by a number of methods as 650 - 680 million years.

THE RIPHAEAN STROMATOLITES

A study of the vertical change in the stromatolite assemblages from the Riphaean deposits of the Southern Urals, the Turukhan uplift and the Uchur-Maya region, whose stratigraphic succession has been established beyond any doubt, suggests that the Riphaean contains three complexes of stromatolites, which regularly replace each other in time. All three complexes occur in the Southern Urals and the Uchur-Maya region, and two (the upper and middle) in the Turukhan uplift.

The lower stromatolite assemblage is characteristic of the Burzyanskaya series (including the Satkinskaya and Bakal' formations) of the Southern Urals and the Uchur series (the Gonam and Omakhtinskaya formations) of the Uchur-Maya regions. In this assemblage there is an extensive development of layered stromatolites of the type Stratifera Korol., of conophytons of the type Conophyton cylindricus Masl. and C. lituus Masl., the closely associated collenias of the type Collenia frequens Walc. and of columnar branching stromatolites of the Collenia kusiensis Masl. group.

In the case of Collenia kusiensis Masl. — the most important form of this assemblage — the characteristic feature is a branching of the type of a simple successive breaking up of a broad stem into narrower stems; the lateral surfaces of the stems are not lined with unit laminar layers. The result is the formation of an uneven and very typical denticulated lateral surface of the structure with annular protuberances that surround the entire column or stem (Figure 1 - 9; Figure 2 - 1). Often the laminae hanging from the stem are joined together, forming "bridges" that connect two or more adjacent stems (Figure 2 - 1), so that these

stromatolites resemble the layered ones. In addition, in the Southern Urals the lower stromatolite assemblage contains numerous and widespread large collenias of the types Collenia symmetrica Walc. and C. columnaris Fent. et Fent., which form bun-shaped bioherms.

The middle assemblage of stromatolites typically is found in the Yurmatinskaya series (the Avzyanskaya formation) of the Riphaean in the Southern Urals, in the upper parts of the Sukhopitskaya series (the Sukhotungusska formation) and the lower part of the Tungsik series (the Derevnya and Burovoy formations) of the Turukhan region and the Yenisey Ridge, as well as in the Maya series (the Yenninskaya, Malgin-skaya, Lakhandinskaya and Tsipandinskaya formations) of the Uchur-May region. This assemblage differs considerably from the lower one. It also contains the widespread columnar "wall-less" branching stromatolites of the Collenia baicalica Masl. group. These are characterized by a simple, usually dichotomous branching with a sharp contraction at the base of the branching shoot. The stems themselves are uneven and knobby, with a club-shaped or tube-rose cross-section that changes vertically along the column. The layers forming the structure (the foliae) do not line the lateral surfaces ("wallless" forms, according to I. K. Korolyuk) and frequently extend in the form of individual peaks which, in contrast to Collenia kusiensis, do not surround the entire stem as rings (Figure 1 - 4, 7, 8; Figure 2 - 4). Along with Collenia baicalica Masl., the middle stromatolite assemblage contains widespread conophytons of the type Conophyton lituus Masl. and related Collenia frequens Walc. (which occurs both in the middle assemblage and in the lower), and also Stratifera Korol., which also occurs in the upper assemblage.

The upper stromatolite assemblage is found in the Karatav series of the Southern Urals (the Min'yarskaya and Simskaya formations), in the upper part of the Tungsik series, in the Oslyanka series (the Shorikhinskaya, Turukhan, Rechka and Furnaya Mys formations of the Turukhan region and their analogues in the Yenisey Ridge), and in the Kurunuryakh formation of the Uchur-May region.

In the upper assemblage the first forms to occur and the ones typical of this community are the columnar, complex branching stromatolites, with a solid lining on the lateral surfaces of the stems produced by the ends of the unit lamellae ("walled" forms, according to I. K. Korolyuk). This lining is the reason for the smooth sides of the stems. The typical representatives of these stromatolites are Collenia buriatica Masl. and C. (Gymnosolen) ramsayi Steinm.

The forms of the Collenia buriatica type (Figure 1 - 1, 2; Figure 2 - 2) are characterized

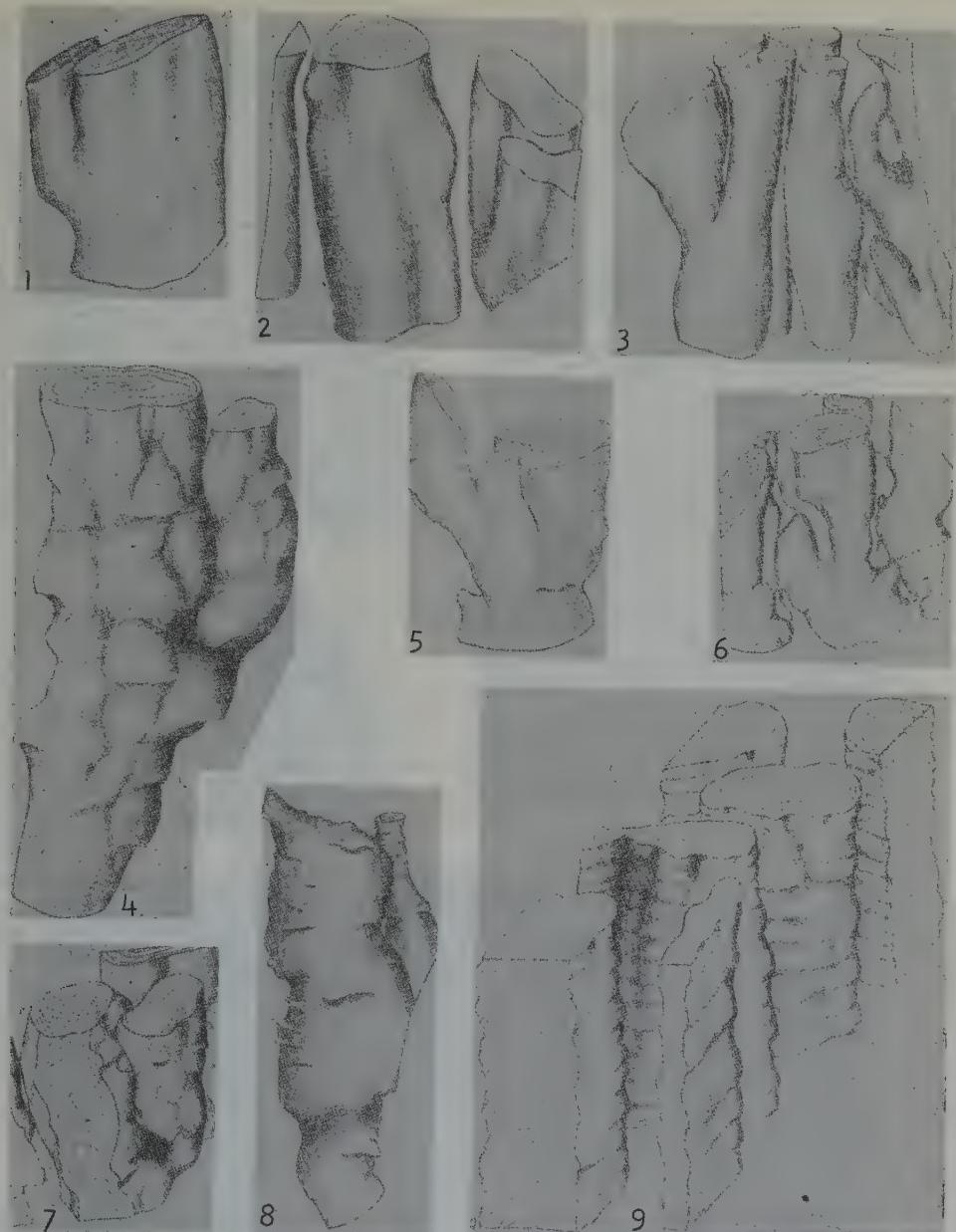


FIGURE 1. The forms of stromatolitic structures:

1 - Collenia buriatica Masl. of the Durnomysskaya formation, Turukhan district; 2 - same, Karatav series, Min'yar formation, Southern Urals; 3 - Collenia (Gymnosolen) ramsayi Steinm., Podynzerskaya formation, Karatav series, Southern Urals; 4 - C. baicalica Masl., Avzyanskaya formation, Southern Urals; 5 - C. (Gymnosolen) ramsayi Steinm., Shorikha formation, Turukhan district; 6 - same, Kurunuryakh formation, Okhotsk massif; 7 - Collenia baicalica Masl., Klyktan formation, Middle Urals; 8 - same, Sukhotungusska formation, Turukhan district; 9 - Collenia kusiensis Masl., Satka formation, Southern Urals.

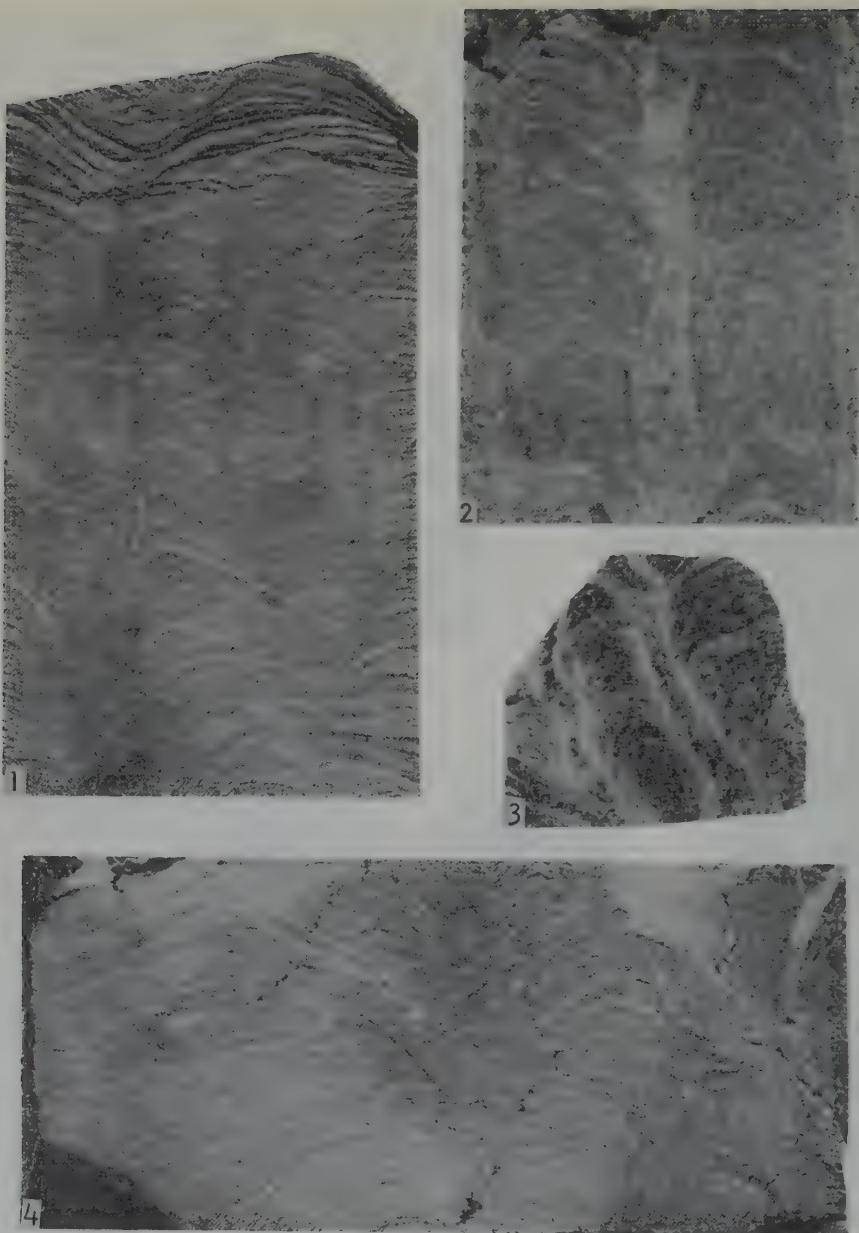


FIGURE 2. The nature of the lamination and the lateral surfaces of stromatolites:

1 - *Collenia kusiensis* Masl., showing the branching out of a broad stem into narrower stems. The laminae hang out from the edge of the stem, forming small cornices. In the upper part of the structure one may see an interconnecting bridge between the stems. Satka formation, Southern Urals. 2 - *Collenia buriatica* Masl., the laminae are crowded against the lateral surface of the stem, forming a "wall" that produces the smooth surface of the structure. Min'yar formation, Southern Urals. 3 - *Collenia (Gymnosolen) ramsayi* Steimn. The laminae densely and repeatedly surround the lateral surface of the stem, forming a thin, multi-layered "wall". Kurunuryakh formation, Okhotsk massif. 4 - *Collenia baicalica* Masl., showing the branching out into two new stems, each with a narrow neck at the base; the laminae overhang from the edge of the stem, forming lips. Avzyanskaya formation, Southern Urals.

by subcylindrical columns or stems which are smooth or very rarely have small knobs; these branch into two and more rarely three new stems, like the branching of tree trunks, without any contraction at the base of the branching column. The laminae that compose the column surround it in a solid mass, forming a "one-layered" wall, in the terminology of I. K. Korolyuk.

The forms of the Collenia (Gymnosolen ramsayi Steinm. type (Figure 1 - 3, 5, 6; Figure 2 - 3) are characterized by very complex branching bent stems of variable diameter, with swellings and contractions. The lamellae comprising the column form a dense coat around it, usually consisting of one layer upon another, forming a "multilayered" wall, in I. K. Korolyuk's terminology. This solid lining of the columns is the reason for their smooth surfaces. In addition, both the upper and the lower assemblages contain smaller numbers of stemmed or columnar stromatolites whose sides are not lined by the lamellae ("wall-less"); these have a multitude of "knobs" and sometimes "bridges", as well as columnar-layered forms.

These same deposits in the Southern Urals contain branching stromatolites with smooth surfaces covered by tiny hummocks due to the uneven, knobby structure of the lamellae forming them. These stromatolites have been very tentatively correlated with Collenia ferrata Grout et Brod. and are transitional forms moving toward the widely distributed stromatolites in the Lower Paleozoic of the Collenia umbella Masl. type and others, which typically have an uneven "vibrating" microlayering. Sometimes also the upper stromatolite assemblage is found to contain forms with lamellae bent into cones; these differ very sharply from the conophyton of the middle and lower levels.

CONCLUSIONS

The change in the three assemblages of stromatolite structures described above, whose succession and direction of change in such widely separated regions as the Southern Urals, the Turukhan and the Uchur-Maya regions, is evidently in no sense to be ascribed to the effect of the facies conditions. It can only be the result of the natural evolution of the stromatolites determined by the evolution of the algal bodies that form stromatolitic structures. For these reasons we may consider the above stromatolite assemblages to be of the same ages, and the series of sediments characterized by them to be three stratigraphic subdivisions of the Riphaean. Of such assemblages, which may be detected in the platform and miogeosynclinal sections through the European part of the U.S.S.R. and Siberia, there are three:

1. The Lower Riphaean (Burzyansk) assemblage includes specific communities of stromatolites, in which, apart from the conophytons, there are collenia of the group Collenia kusiensis group. This complex of rocks is most typically represented by the Burzyansk series of the Urals; in Siberia it appears as the Uchur series of the Uchur-Maya region. In other areas it is distinguished by its stratigraphic position (the Teyskaya series of the Yenisey Ridge).

There are still no data on the age of the Lower Riphaean in the Urals. In any case, it is older than 1260 million years, on the basis of figures for the Middle Riphaean obtained from glauconites, and the older granites of the Berdyauzhskiy massif (age 1350 million years) that intrude them. Their age may perhaps be close to the age of the Iotnian. The Gonam formation of the Uchur-Maya region is dated at 1500 million years.

2. The Middle Riphaean (Yakutsk) assemblage is also characterized by large conophytons, but in addition to these it contains an abundance of collenia of the Collenia baicalica Masl. type. The Middle Riphaean rocks are the most widespread. In the Southern Urals they are represented by the Yurmatinskaya series, which emerges into the eastern part of the Russian platform (the Serafimovskaya formation). The Middle Riphaean is clearly distinguished in the Turukhan region and on the Yenisey Ridge, where it is represented by the Sukhoptitskaya and the lower part of the Tungusik series (up to the bottom of the Shorikhinskaya or the Serry Klyuch formation), and also on the Aldan shield, where it corresponds precisely to the Maya series. Apparently the Middle Riphaean includes the Goloustenskaya and the Uluntuy-skaya formations of the Baykal area and the Tszisyuan Kitay series. From analysis of the glauconites, the absolute age of the Middle Riphaean has been determined as 1000 - 1300 million years.

3. The Upper Riphaean ('Timan') assemblage differs from the two preceding in the sharp decrease or even complete disappearance of the conophytons, and in the predominance in the section of columnar branching ("walled") stromatolites of the types Collenia ramsayi Steinm. and C. buriatica Masl.

In the Southern Urals the Upper Riphaean includes the Karatayev series, on the Russian platform the Kaverinskaya and Serdobskaya series, in the Turukhan region and the Yenisey Ridge the upper part of the Tungusik series (from the bottom of the Shorikhinskaya formation) and the Oslyanka series, and along the eastern margin of the Aldan shield the Uyskaya series and the Kurunuryakh formation. It should not be extended to include the Sinian Tszinbaykou series of China, whose absolute age is 870 - 900 million years.

The absolute age of the Upper Riphaeen, according to the potassium-argon method, is reckoned at 600 - 1000 million years. Moreover most of the figures give two distinct levels; the lower is at 850 - 900 and the upper at 650 - 750 million years.

The problem of where to draw the upper boundary of the Riphaeen group cannot be considered settled; it depends on where one assigns the Valday series of the Russian platform and its analogues (the Ashinskaya series of the Urals, the Varyazh series of the Norwegian Caledonian area, etc.). The Valday series, whose absolute age is 550 - 650 million years, occurs beneath the Baltic series, which contains the first fauna to appear on the Russian platform (trilobites, gastropods, etc.). It would be proper to assign the Valday series to the Riphaeen if it did not contain a complex of pollen very closely resembling that found in the Cambrian Baltic series. The data are still insufficient for a final solution to the problem of where the Valday series belongs. It may be tentatively placed within the Cambrian system.

The data obtained on the absolute age and the stratigraphic correlation of the Riphaeen group suggest the following:

1. The Riphaeen is a group of strata extending over a time of 700 million years; its duration exceeds that of the Paleozoic, Mesozoic and Cenozoic taken together. There is no basis for assigning the Riphaeen group or any of the series composing it to the Paleozoic.

2. A study of the vertical distribution of the stromatolites shows that the type of structure of the stromatolites changes in a consistent direction through the sections in Siberia and the Urals. These data, controlled by absolute age figures, provide the basis for a three-fold subdivision of the Riphaeen group.

3. The results obtained also show that the method of correlating the Riphaeen by cycles of sedimentation, which can be used successfully between quite large regions which sometimes embrace an entire platform, is unsuitable for correlating sections from different platforms.

4. The Urals stratotype, as compared to the sections through Siberia and China, contains the greatest number of formations of all three subdivisions of the Riphaeen, with rich assemblages of stromatolites. The most recent data have shown that the hiatus between the Riphaeen and the Paleozoic in the Urals is considerably smaller than in China, where it reaches 400 million years. There is no doubt that the Urals section is to be taken as the stratotype for the Upper Proterozoic.

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Geology of the Academy of Sciences of the
U. S. S. R., Moscow

Received, 30 May 1960

THE STRATIGRAPHY OF THE FAMENNIAN AND LOWER TOURNAISIAN DEPOSITS

IN THE MUGODZHARY AND ADJACENT AREAS OF THE URALS¹

by

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The unified stratigraphic scheme of the Devonian deposits of the Russian platform and the western slopes of the Urals, as adopted in 1951, contains a detailed stratigraphic subdivision of the Famennian deposits on the western slopes of the Urals. On the eastern slopes, however, these deposits have been less thoroughly studied: the most complete sections of Famennian deposits, as characterized by their faunal contents, are found here in two places — in the vicinity of Verkhneural'sk and in the Berchogur trough. In the first of these sections the Famennian deposits, first studied here by A. P. Karpinskiy [10], are represented by limestones containing Cyrtospirifer archiaci (Murch.) and the overlying goniatite-Clymenia limestones, within which E. Ya. Perna [26, 27] has distinguished the Cheiloceras, Prolobites and Annulata subdivisions of the Famennian stage; the goniatite-Clymenia limestones of this section have been repeatedly correlated with Famennian deposits of similar facies in other areas of the Urals [22, 23]. The second section through the Famennian deposits on the eastern slopes of the Urals — in the Berchogur trough, which will be discussed in this article — is represented by essentially different facies.

The first stratigraphic scheme for the Famennian deposits of the Berchogur trough was proposed by D. V. Nalivkin [21], who studied the spores described by V. I. Yavorskiy and reviewed the analyses of the fauna made earlier by P. N. Benyukov [6] and A. N. Nifontov [25]. D. V. Nalivkin's scheme contains the following subdivisions, from bottom to top:

1) a suite of conglomerates and limestones with Frasnian fauna; 2) a suite of sandstones, conglomerates and limestones with Famennian fauna: a) limestones with Spirifer aff. calcaratus Sow. — the lower stratum (Berchogur) developed on the eastern margin of the Berchogur trough, b) limestones and conglomerates with S. whitneyi Hall — the upper beds (Karganda) developed in the central part of the

Berchogur trough and along its western margin; 3) limestones with transitional Devonian-Carboniferous fauna.

This scheme was adopted by G. I. Vodorezov, whose numerous collections have unfortunately not been studied. The beds identified by D. V. Nalivkin as transitional between Devonian and Carboniferous have come to be known in the literature on the Mugodzhary as the Dzhangana formation [2], which has been studied in detail by Ye. A. Balashova, who distinguished four packets of beds within it on the basis of the fauna. In the lowermost of these, for the first time in the Mugodzhary, she found goniatites of the Gattendorfia zone [3, 4, 5]. Nevertheless the boundary between the Devonian and Carboniferous adopted by Ye. A. Balashova has remained too indefinite.

The data obtained by the present writer directly supplement Ye. A. Balashova's investigations, and also provide the basis for a wider correlation of deposits of the same age in other regions.

The formation set forth here was obtained by the author of the present article in studying the sections and the brachiopod fauna² of the Famennian and Tournaisian deposits in the period from 1955 to 1957; the microfauna were studied by Ye. A. Reylinger and the goniatites by B. I. Bogoslovskiy.

Within the Berchogur trough the Famennian deposits may be traced along the margins, where they are fringed by outcrops of Frasnian deposits and are exposed in the center of the trough, forming the Kurgandzhar uplift. The Famennian deposits transgressively overlie the Frasnian,

²Descriptions of the new species of Rhynchonellacea identified by the author and mentioned below will be found in the collection, "New Species of Ancient Plants and Invertebrates of the U.S.S.R.", Part I, Gosgeoltekhnizdat, 1960. The names of the genera of Rhynchonellacea follow the revised edition of "Osnovy Paleontologii" ("Principles of Paleontology") (in litt.).

¹Stratigrafiya famenskikh i nizhneturneyskikh otlozheniy Mugodzhar i smezhnykh rayonov Urala.

but without any noticeable angular unconformity. They are represented by clastic-carbonate rocks of variable facies, whose thickness ranges from 80.0 in the carbonate sections to 397.8 m in the sections composed predominantly of clastic rocks: conglomerates and sandstones. At the top they are conformably overlain by Lower Tournaisian deposits, some 248.5 m thick, represented by limestones and smaller amounts of carbonate-clastic rocks.

The most complete sections through the Famennian and Lower Tournaisian deposits, which are supported by paleontological data, occur on the western flank of the trough, at Mt. Alabas, in the central Kurgandzhar uplift (along the upper reaches of the Kurgandzhar River) — and on the eastern flank, along the Dzhangan-Say River, a right tributary of the Chuuldaik River (Figure 1).

In correlating the main sections through the Berchogur trough, as listed above (Figures 1, 2), one may distinguish four levels, characterized by the following paleontological assemblages:

First: Schizophoria praessimma Hall, Productella kirgisica Wen., Plicatifera mugodjarica (Nach.), Pugnax janischevskii sp. nov., occasional single Yunnanellina mugodjarica sp. nov., Cyrtiopsis wenjukowi sp. nov., Cyrtospirifer archiaci (Murch.); in thin sections Ye. A Reylinger has found the alga Girvanella sp. and rare foraminifera Schuguria sp. and Parathurammina cushmani Sul.

Second: Stropheodonta intertrialis Phill., Schizophoria impressa Hall, Streptorhynchus matyricus Nal., Chonetes sp., Plicatifera mugodjarica (Nach.), Nudirostra ursus (Nal.), Pseudonudirostra uralica (Nal.), Yunnanellina mugodjarica sp. nov., Cyrtospirifer archiaci (Murch.), Cyrtiopsis wenjukowi sp. nov. (rare), Athyris angelica Hall, A. sulcifera Nal. and single specimens of Ambocoelia urei (Flem.); in thin sections Ye. A. Reylinger has identified the alga Girvanella sp., the foraminifers Archaeosphaera sp. and Vicinisphaera squalida Antr. and, in the upper part of the stratum, rare specimens of Endothyra sp. and Bisphaera minima Lip.

Third: Aulacella interlineata (Sow.), Schizophoria impressa Hall, rare specimens of Plicatifera ex gr. praelonga (Sow.), Camarotoechia intercalata sp. nov., Nudirostra plicata sp. nov., Pseudonudirostra posturalica sp. nov., P. plano-ovalis (Nal.), Yunnanellina sp. nov., Plectorhynchella markovskii sp. nov., P. uralica (Nal.), Pugnax biloba sp. nov., P. asiatica sp. nov., Cyrtospirifer ex gr. lebedianicus Nal., C. whitneyi (Hall), Mucrospirifer posterus subsp. mesaplicatus subsp. nov.³

new species of the genus Guerichella (in coll.), Ambocoelia urei (Flem.) and Athyris ex gr. postangelica Nal.; in thin sections Ye. A. Reylinger has observed: the algae Rhadoporella melekesensis Kul. and the foraminifera: rare Endothyra ex gr. communis Raus., Schuguria flabelliformia Antr., Evolutina sp., Parathurammina sp., Bisphaera sp. and Ammobaculites sp.

The fourth level is subdivided into three packets of beds: the first (lower) has Chonetes cf. parvus Jan., Productus (Spinulicosta) concentrica Hall, Plicatifera kassini Nal., Productus (Linopodus) laevicostus White, Camarotoechia panderi (S. et M.), Cyrtospirifer ex gr. julii (Dehée), numerous Brachythrys suborbicularis var. tenuicostata Nal. (in coll.), and Ambocoelia urei (Flem.); in thin sections Ye. A. Reylinger has found the alga Rhabdoporella melekesensis Kul. and rare foraminifera Endothyra ex gr. communis Raus.

The second (middle) packet contains Chonetes sp., Productus (Spinulicosta) concentrica Hall, Plicatifera niger (Goss.), Camarotoechia panderi (S. et M.), Spirifer tornacensis Kon., Ambocoelia urei (Flem.), Athyris puschiana Vern., numerous rugose corals such as Caninia ussovi (?) Gab. and others, and stromatoporids, gastropods and ostracodes; in thin sections Ye. A. Reylinger has discovered the foraminifera Endothyra communis regularis Lip., Quasiendothyra kobeitusana Raus., Septatournayella njumolga Durk., and S. potensa Durk.

The third (upper) packet has Plicatifera niger (Goss.), Spirifer tornacensis Kon., Syringothyris ex gr. missouri H. et G., S. ex gr. hannibalensis (Swallow), Ambocoelia unionensis Well.; among the goniatites B. I. Bogoslovskiy has identified Imitoceras intermedium Schind., I. subbilobatum (Muenster) and I. substriatum (Muenster); among the foraminifera Ye. A. Reylinger has found single small Endothyra ex gr. communis Raus.; numerous rugose corals are still unidentified.

The first two levels are correlated with the beds known in the brachiopod facies of the Famennian deposits on the western slopes of the Urals: the first level, containing numerous Cyrtiopsis wejukowi sp. nov. and Cyrtospirifer archiaci (Murch.) corresponds to the Makarov beds; the second, characterized by the presence of Nudirostra ursus (Nal.) and other species, is the analog of the Murzakayev beds.

The third level, or uppermost level of the Famennian deposits, characterized by a peculiar brachiopod assemblage, the present author has distinguished under the name of the Kurgandzhar beds.

The fourth level (Lower Tournaisian deposits), subdivided into three packets, I have

³Lamellispirifer posterus, according to D.V. Nalivkin [21, p. 110, Plate XXIV, Figure 15].

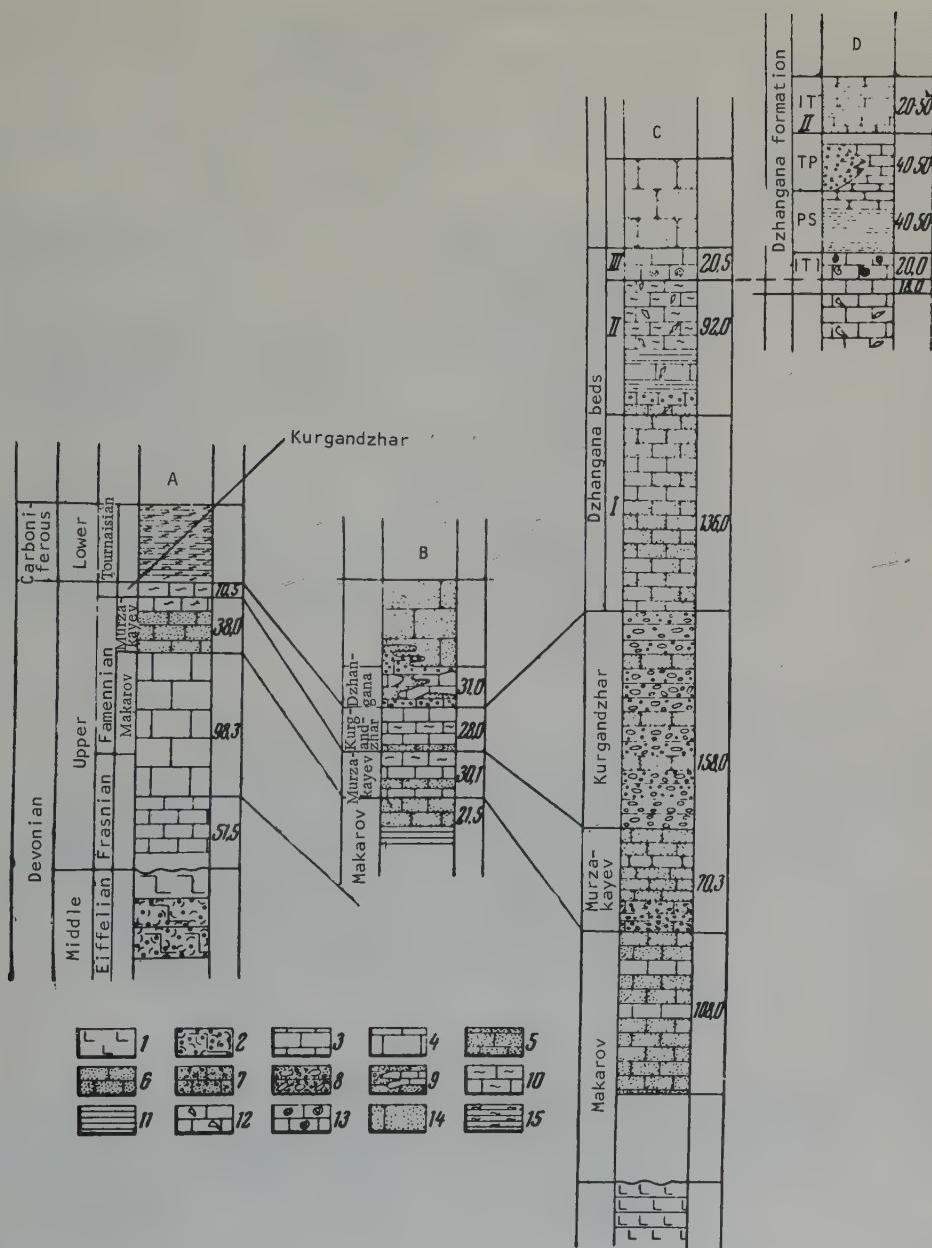


FIGURE 1. Diagram comparing the sections through the Famennian deposits and the boundary deposits of the Tournaisian in the Berchogur trough;

A - western margin of the Berchogur trough, Boll'shoy Alabas; B - Central Kurgandzhar uplift, upper reaches of the Kurgandzhar River; C - eastern margin of the Berchogur trough, Dzhangana-Say River; D - section through the Dzhangana formation, after Ye.A. Balashova (1954). I, II and III - first, second and third packets of Dzhangana beds (Dzhangana-Say River section). Lithologic designations: 1 - spilites, diabases and jaspers; 2 - porphyrites, tuffites and tuff conglomerates of porphyritic composition; 3 - limestones; 4 - massive algal limestones; 5 - sandy limestones; 6 - calcareous sandstones; 7 - calcareous gravelites; 8 - conglomerates; 9 - reef limestones; 10 - marly limestones; 11 - siltstones; 12 - coral limestones; 13 - brachiopod-goniatite limestones; 14 - graywackes; 15 - argillites.

System	Series	Stage	Substage	Biostratigraphic zones and levels	Southern Mugodzhary			
					Berchogur trough			
Carboniferous	Lower	Tournaisian	According to the unified scheme of 1951	Beds Upa	Beds Dzhangana	Packets Second	Rhynconellids	Microfauna
		Likhvinian				Third	Limestones with <i>Spirifer tornacensis</i> , <i>Syringothyris hannibalis</i> , <i>Jmitoceras subbivalvatum</i> Münst.	Isolated, compressed <i>Endothyra communis</i>
		Malev				First	Limestones with <i>Camarotoechia panderi</i> (S. et M.), <i>Spirifer tornacensis</i> Kon., <i>Athyris puschiana</i> Vern., with numerous rugosae, etc.	<i>Septatournayella njumolga</i> Durk., <i>Quasiendothyra kobeitu sanna</i> Raus., <i>S. potensa</i> Durk., <i>Endothyra communis regularis</i> Lip.
Devonian	Upper	Famennian	Zone containing Laevigites	Kurgandzhar	Sandy limestones (in places sandstones and conglomerates) with <i>Aulacella interlineata</i> (Sow.), <i>Pseudonudirostra posturalica</i> gen. et sp. nov., <i>P. planovalvis</i> (Na 1.), <i>Camarotoechia intercalata</i> sp. nov., <i>Pleatorhynchella (Monticola) markovskii</i> sp. nov., <i>Cyrtospirifer whitneyi</i> Hall, C. ex gr. <i>lebedianicus</i> Na 1.		Camarotoechia intercalata sp. nov., <i>Pseudonudirostra posturalica</i> sp. nov., <i>P. planovalvis</i> (Na 1.), <i>Pleatorhynchella markovskii</i> sp. nov., <i>P. uralica</i> (Na 1.), <i>Yunnanellina kurgandzharica</i> sp. nov., <i>Pugnax biloba</i> sp. nov.	Rare <i>Endothyra communis</i> , <i>Umbella</i> sp., <i>Girvanella</i> sp., <i>Rhabdoporella melekesensis</i> Kul.
	Lower Famennian		Zone containing Prolobites and Liornynchus ursus Nal.	Murzakayev	Sandy limestones with <i>Nudirostra (Liorhynchus) ursus</i> (Na 1.), <i>Pseudonudirostra (=L.) uralica</i> (Na 1.), <i>Yunnanellina mugodjarica</i> , sp. nov., <i>Cyrtospirifer archiaci</i> (Murch.), C. ex gr. <i>sulcifer</i> (H. et C.) etc.		<i>Nudirostra (=L.) ursus</i> (Na 1.), <i>Pseudonudirostra (=L.) uralica</i> (Na 1.), <i>Yunnanellina Mugodjarica</i> sp. nov.	Rare <i>Endothyra communis</i> Raus., <i>Vicinisphaera squalida</i> Antr. <i>Girvanella</i> sp., <i>Schuguria</i> sp., <i>Parathurammina cushmani</i> Sul.
Frasnian	Upper Frasnian		Zone containing Cheilocesar, Liorhynchus polonicus Gürich and Cyrtospirifer archiaci (Murch.)	Makarov	Limestones, sandstones and siltstones with <i>plicatifera mugodjarica</i> (Nach.), <i>Pugnax janischevskii</i> sp. nov., <i>Cyrtospirifer archiaci</i> (Murch.), <i>Cyrtiopsis wenjukowi</i> sp. nov.		<i>Pugnax janischevskii</i> sp. nov.	<i>Schuguria</i> sp.
	Zone containing Crickites ex pectatus Wdkd.			Barma	Limestones with <i>pugnoides triaequalis</i> (Goss.) (after B.P. Markovskiy), <i>Theodosia anossifi</i> (Vern) etc.		<i>Pugnoides triaequalis</i> (Goss.) (after B.P. Markovskiy)	

Beds	Southern Urals, Zingan R., V.N.Krestovnikov, 1948; D.V. Nalivkin, B.P. Markovskiy, 1937 (Sramenskiy section).	Middle Urals, Vil'ya R. O.A. Lipina, 1951	Middle Pechora area, A.V. Durkina, 1959
6-7	Limestones with <i>Spirifer (Paulonia) mediocris</i> Leb.		
4-5	Limestones with <i>Cymaclymenia cf. camerata</i> , <i>Cyrtospirifer jullii</i> , <i>Spirifer tornacensis</i>	Limestones with <i>Bisphaera</i>	<i>Bisphaera malevken-sis</i> Bir., <i>Chonetes malevkenensis</i> Sok., <i>Camarotoechia panderi</i> (S.et M.), <i>Ambocoelia urei</i> (Flem.) etc.
1-3	Limestones with <i>Phacops accipitrinus</i> , <i>Endothyra communis</i> , <i>E. primaeva</i>	Zone containing <i>Endothyra communis</i> and <i>Quasiendothyra kobeitusana</i>	<i>Maiev-Upa beds</i> <i>Septatournayella njumolga</i> , <i>S. potensa</i> <i>Endothyra communis</i> and <i>Quasiendothyra kobeitusana</i> , <i>Chonetes malevkenensis</i> Sok., <i>Spirifer aff. tornacensis</i> Kon. Gap?
	Limestones with <i>Productus speciosus</i> Hall, <i>Camarotoechia omaliusi</i> , <i>Spirifer posterus</i> H. et C., <i>S. barumensis</i> Sow.	Zone containing <i>Septatournayella</i> <i>Rare Endothyra communis</i> , <i>Liorhynchus baschkiricus</i> (Tschern.), <i>Posidonia venusta</i> Müst.	<i>Upper Famennian</i> <i>Limestone</i> and (in the upper part of the section) dolomites: at the top, organogenic limestones containing <i>Archaeospaera crassa</i> Lip., <i>Vicinesphaera angulata</i> Antr., with isolated <i>Septatournayella rauserae</i> Lip. and <i>Endothyra communis</i> Raus.
	Limestones with <i>Liorhynchus ursus</i> . Na I., <i>Cyrtospirifer ex gr. verneuilli</i> (Murch.)	Zone containing <i>Septatournayella</i> <i>Rare Endothyra communis</i> , <i>Liorhynchus ursus</i> Na I.	<i>Dankovo-Lebedyanck</i> Marls, limestones and clays with <i>Camarotoechia cf. grisica</i> Na I., C. ex gr. <i>Iivonica</i> Buch, <i>Cyrtospirifer lebedianicus</i> Na I.
	Limestones with <i>Liorhynchus polonicus</i> Gürich, <i>Pugnax aff. tridentatus</i> Na I., <i>Monticola ovalis</i> Na I., <i>Spirifer posterus</i> H. et C.		

FIGURE 2. A correlation diagram of the Famennian and Lower Tournaisian deposits of the Southern Mugodzhary and other regions of the Urals

assigned to the Dzhangana beds. The third, or upper, packet of the Dzhangana beds in the section studied by the present writer corresponds to the packet of goniatite limestones (IT 1) identified by Ye. A. Balashova [3, 4, 5] at the base of the Dzhangana formation (Figure 1, sections C and D).

Thus within the section through the Famennian deposits in the Berchogur trough one can distinguish the Makarov, the Murzakayev and the Kurgandzhar beds; at the top of the last subdivision are the Lower Tournaisian Dzhangana beds.

The Makarov beds in the Berchogur trough differ from the type Makarov beds on the western slopes of the Southern Urals by the absence of *Zilimia polonica* (Guerich) and by the peculiar composition of its fauna. *Cyrtiopsis wenjukowi* sp. nov., the most common species in the Makarov beds in the Berchogur trough, closely resembles *Cyrtospirifer murchisonianus* from the Famennian deposits of Armenia [1], on the one hand, and also *Spirifer murchisonianus* from the Famennian deposits of the Pamirs [31], on the other. *Cyrtospirifer archiaci* (Murch.) is very similar to the Voronezh *C. archiaci*, but shows more individual variety in its forms. *Plicatifera mugodjarica* (Nach.) and *Productella kirgisica* (Wen.) are topotypes of the forms described by G. Nakhimson [24] and P. N. Benyukov [6]. The lower part of the section through the Makarov beds (on the Kurgandzhar uplift) contains very many *Pugnax janischevskii* sp. nov., which in places occupy almost the whole volume of the sandstones.

The occurrence of numerous *Cyrtospirifer archiaci* and the fact that they are underlain by beds containing *Nudirostra ursus* (Nach.) allow the Makarov beds in the Berchogur area to be correlated with the Makarov beds on the western slopes of the Southern Urals, corresponding to the goniatite limestones of the *Cheiloceras* zone. The Makarov beds of the Berchogur trough are also correlated with the undivided Zadon-Yelets beds of the Volga-Urals region, which contain a scanty fauna of brachiopods, mainly *Cyrtospirifer archiaci*; in the section of the Baytugan exploratory test well, however, V. N. Krestovnikov has found that the Zadon-Yelets beds contain *Chonetes nanus* Vern., *Plicatifera mugodjarica* (Nach.), *C. archiaci* (Murch.), *Athyris concentrica* Buch. and others, so that the Lower Famennian beds of the Southern Mugodzhary can be correlated with the latter. Although the Lower Famennian *Cyrtospirifer archiaci* of the Mugodzhary closely resembles *C. archiaci* from the Central Devonian field, a more complete correlation of the Makarov beds of the Berchogur trough with the Zadonian beds of the Central Devonian field cannot be made, since the latter contain an abundant fauna of

Camarotoechia, which is unknown in the Lower Famennian of the Mugodzhary.

The Murzakayev beds of the Berchogur trough are characterized by a more varied fauna, in which the rhynchonellids are common and widespread: representatives of the genera *Nudirostra* Copper et Muir-Wood (= *Liorhynchus* Hall), *Pseudonudirostra* gen. nov. (*Liorhynchus* Hall, in part) and *Yunnanellina* Grabau. *Pseudonudirostra uralica* (Nal.) and *Yunnanellina mugodjarica* sp. nov., which together with *Nudirostra ursus* (Nal.) form a peculiar assemblage of rhynchonellids, have acquired the status of index fossils for the Murzakayev beds of the Mugodzhary. *Pseudonudirostra uralica* and *Yunnanellina mugodjarica* are still considered to be specifically local Mugodzhary species, owing, no doubt, to the insufficient study of the Famennian brachiopods of the Urals.⁴

Plicatifera mugodjarica and *Cyrtiopsis wenjukowi* sp. nov., transitional forms from the Makarov beds, have a limited distribution here.

B. P. Markovskiy, who identified the Murzakayev beds on the western slopes of the Southern Urals, has correlated the latter with the cephalopod limestones of the *Prolobites* zone, observing that *Nudirostra* (= *Liorhynchus*) *ursus* (Nal.) is sometimes encountered together with *N.* (= *L.*) *baschkirica* (Tschern.). In the Bakay trough (NNW from the Berchogur trough), in the cephalopod limestones of the *Prolobites* zone, the present author has found *Nudirostra baschkirica* and single specimens of *N. ursus*. The beds in the Berchogur trough that contain *N. ursus* may therefore be reliably correlated with the Murzakayev beds of the western slopes of the Southern Urals.

The occurrence of *Yunnanellina mugodjarica* sp. nov. in the Murzakayev beds of the Southern Mugodzhary suggests that the Mugodzhary basin was at that time connected with the Kazakhstan basin of the same age, in the deposits of which close representatives of this genus have been found. On the whole, the Murzakayev beds of the Southern Mugodzhary may be very distantly correlated with the *sulcifer* beds⁵ of the Famennian stage of Central Kazakhstan, containing widespread *Cyrtospirifer sulcifer* (H. et C.), which is very rare in the

⁴The collection made by E. Ya. Perna (eastern slopes of the Urals, near Verkhneural'sk) contains forms very closely resembling *Y. mugodjarica*, but identified as *L. uralicus* Nal. (F. N. Chernyshev Central Museum of Geology).

⁵The extent of the *sulcifer* beds is taken after M. V. Martynova [16], who assigns the upper part of the *Sulcifer* beds, as identified by D. V. Nalivkin [20], to the Kara-Kingir beds.

Mugodzhary, as well as Camarotoechia turanica (Rom.) and Plicatifera semisbugensis Nal., which are completely unknown in the Mugodzhary.

In their stratigraphic position the Murzakayev beds correspond to the lower part of the Dankovo-Lebedyansk beds of the Volga-Urals region; the latter contain a very scanty brachiopod fauna — Chonetes sp., Monticula sp., Camarotoechia ex gr. livonica Buch and Cyrtospirifer ex gr. archiaci (Murch.) — so that it is difficult to make a fuller correlation. Because of the occurrence, in the faunal assemblage of the Dankovo-Lebedyansk beds of the Central Devonian field, of representatives of the genus Camarotoechia H. et C., which is unknown in the Murzakayev beds of the Mugodzhary, the latter cannot be correlated with the Dankovo-Lebedyansk beds. This view is supported by the absence in the latter of representatives of the genera Nudirostra Copper et Muir-Wood, Pseudonudirostra gen. nov. and Yunnanellina Grabau.

The Kurgandzhar beds are distinguished by a brachiopod faunal content of considerably new and peculiar composition. Among the rhynchonellids, which predominate in this assemblage, along with the further development of genera occurring lower in the section — Nudirostra Copper et Muir-Wood, Pseudonudirostra gen. nov. and Yunnanellina Grabau — representatives of Camarotoechia H. et C., Zilimia Nal. and Plectorhynchella Copper et Muir-Wood (= Monticola Nal.) make their first appearance, and Pugnax H. et C. is widespread.

Pseudonudirostra posturalica sp. nov. is a further development of P. uralica from the Murzakayev beds. Pseudonudirostra planovalvata (Nal.) shows a striking similarity to Liorhynchus planovalvis as described by D. V. Nalivkin [20] and A. M. Simorin [29] in the upper part of the sulcifer beds of Kazakhstan. Camarotoechia intercalata sp. nov. is, apparently, related to the Famennian predecessors of C. pleurodon (Phill.), which is widespread in the Lower Carboniferous deposits of the Urals, the Donets Basin and Armenia. Plectorhynchella uralica (Nal.) (in coll.) has been described by D. V. Nalivkin in the Lower Tournaisian deposits of the more northern areas of the Urals. P. markovskii sp. nov. is very similar to Camarophoria (?) ferganensis, identified by M. E. Yanishevskiy in the Lower Tournaisian deposits of Fergana [30]. Pugnax biloba sp. nov. is close to the typical Lower Carboniferous P. acuminata (Mart.); P. asiatica sp. nov. is also, evidently, the source of the Carboniferous P. acuminata var. plicata Sow., which is very similar to forms described in the Lower Tournaisian of Fergana [30] and the Upper Famennian of the Pamirs [31]. Among the spiriferacea in the lower part of the Kurgandzhar beds there is Cyrtospirifer ex gr.

lebedianicus Nal., which very closely resembles the forms of the same name from the Stalingrad area described by A. K. Krylova [12], and differs from the Voronezh type forms only in lacking the middle furrow on its protuberance. The upper part of the section contains Cyrtospirifer whitneyi (Hall), which is close to the American topotype (Central Geological Museum, Coll. 1493); there are also widespread Mucrospirifer posterus subsp. mesaplicatus subsp. nov.⁶, new species of the genus Guerichella, and Ambocoelia urei (Flem.), which is very similar to the forms of the same name from the Malev stratum of the Moscow Basin [28] and to A. gregaria var. asiatica Reed from the Famennian deposits of the Pamirs [31].

On the basis of their occurrence over the beds with Nudirostra ursus, and according to some other similar species — Pseudonudirostra planovalvis (Nal.), which resembles Pugnax (?) plana Nal. (in coll.), Mucrospirifer posterus (H. et C.), Ambocoelia urei (Flem.) and others — the Kurgandzhar beds correspond to the Upper Famennian deposits along the Sikaza River [19], which D. V. Nalivkin has correlated with the brachiopodgoniatite beds of the Laevigites zone in the sections along the Ryuzyak River [19]. It must be stressed, moreover, that the brachiopod assemblage of the Kurgandzhar beds is more varied than those in the comparable deposits on the western slopes of the Southern Urals (the Sikaza and Ryuzyak Rivers). According to their position in the section and the occurrence of many common forms — Pseudonudirostra planovalvis (Nal.) and others — the Kurgandzhar beds are correlated with the upper part of the sulcifer beds in Northeastern Kazakhstan [20, 29]. There are greater obstacles to the correlation of the Kurgandzhar beds with Upper Famennian deposits of the Volga-Urals region and the more western areas of the Russian platform, since the latter contain a very scanty brachiopod fauna and the Kurgandzhar beds have a sparse microfauna, which has served as the chief basis for the subdivision of the Upper Famennian deposits of the Volga-Urals and more western regions.

The presence of rare specimens of Endothyra ex gr. communis Raus and the development of Rhabdoporella melekesensis Kul. in the Kurgandzhar beds does not contradict their correlation with the beds of the Volga-Urals region which O. A. Lipina [15] has assigned to the Septatournayella rauserae Lip. zone.

Returning to the first stratigraphic scheme of the Famennian deposits in the Berchogur trough, prepared by D. V. Nalivkin [21], it should be

⁶Lamellispirifer posterus, according to D. V. Nalivkin [21, p. 110, Plate XXIV, Figure 15].

noted that the Makarov beds distinguished by the present author, according to the composition of their fauna, correspond more closely to the Berchogur strata (lower) in D. V. Nalivkin's scheme, and our Kurgandzhar beds to his Karaganda (upper) strata. This correspondence, however, is far from complete, for the following reasons.

In the section through the Famennian deposits along the eastern margin of the Berchogur trough (along the Dzhangan-Say River) we have encountered Nudirostra (= Liorhynchus) uralica (Nal.), which in D. V. Nalivkin's scheme is characteristic not of the Berchogur, but of the Karaganda level. D. V. Nalivkin's mention of the presence of Camarotoechia aff. letiensis (Goss.) in the deposits of the Berchogur level on the eastern margin also testifies to the development on the eastern margin of Famennian deposits that are younger than the Berchogur level identified here by D. V. Nalivkin, since Camarotoechia occurs in the uppermost (Kurgandzhar, according to our scheme) beds of the Famennian stage. Finally, the occurrences of Yunnanellina mugodjarica sp. nov. in the Famennian deposits of the eastern slopes (on the left bank of the Miy-Bulak, a right tributary of the Chuudlak River) supplement the evidence indicating that the Famennian deposits on the eastern flank of the Berchogur trough correspond not only to the lower Berchogur (in D. V. Nalivkin's scheme), but also in part to the upper, Karaganda stratum identified by D. V. Nalivkin on the western slopes in the central part of the trough.

On the other hand, in the fauna of the Karaganda stratum D. V. Nalivkin found species characteristic of both the Murzakayev beds identified by the present writer — Pseudonudirostra (= Liorhynchus) uralica (Nal.), Chonetes nana Vern., Productella subaculeata var. kirgisica Wen., Athyris concentrica Buch and others — and the younger Kurgandzhar beds — Pseudonudirostra plano-ovalis (Nal.) (identified by D. V. Nalivkin as Liorhynchus numismalis Nal. in coll.), numerous Plectorhyncella (= Monticola), Cyrtospirifer whitneyi (Hall), Mucrospirifer posterus Hall, etc. For this reason in comparing the fauna discovered in the section with the fauna attributed by D. V. Nalivkin to the Berchogur (lower) and Karaganda (upper) strata [21], the present writer has come to the conclusion that the distinction between these two levels does not fully correspond to the section through the Famennian stage in the Berchogur trough.

The Dzhangan beds (Lower Tournaisian): it is of great interest to compare the Dzhangan beds with the sections on the western slopes of the Urals: the Zigan River (Southern Urals), the Vil'va River (Middle Urals) and the Pechora area.

Along the Zigan River, V. N. Krestovnikov has distinguished transitional beds containing Cyrtospirifer julii (Dehéé), Phacops bergicus Drev. and Cymaclymenia cf. camerata Schind. (beds 1 - 5), which he has correlated with the Etroeungtian zone of the Belgian basin, and limestones with Spirifer (Paulonia) Medius Leb. and Productus scabridulus Mart. (beds 6 - 10), which he has assigned to the Lower Tournaisian of the Gattendorfia zone [11]. The first and second packets of the Dzhangan beds (Figure 1, C), according to their position in the section and their content of certain similar and common species — Cyrtospirifer ex gr. julii (Dehéé), C. ex gr. trapezoidalis Krest. et Karp., Spirifer tornacensis Kon. and Plicatifera niger (Goss.) — correspond to the transitional beds of the Zigan section (beds 1 - 5, after V. N. Krestovnikov) (Figure 2). In the corresponding part of the Dzhangan section Ye. A. Reylinger has found rare Endothyra ex gr. communis in the first packet, and E. communis regularis Lip., Quasiendothyra kobeitusana Raus., Septatournayella njumolga Durk. and S. potensa Durk.

Although we may in general stress the correspondence between the first (lower) and second packets of the Dzhangan section and the transitional beds (1 - 5) of the Zigan section, we must note the different distributions of some similar species in the two sections: for example, Cyrtospirifer ex gr. julii, found in the first Dzhangan packet, is characteristic of the upper part of the transitional beds in the Zigan section (beds 4 - 5, according to V. N. Krestovnikov).

With the upper beds (6 - 7) of the Zigan section has been correlated the third (uppermost) packet of the Dzhangan section, which contains goniatites of the Gattendorfia zone (Figure 1, C).

Farther north, along the Vil'va River, O. A. Lipina has identified the Famennian deposits of the Septatournayella rauserae Lip. zone, a zone of Endothyra communis Raus. and Quasiendothyra kobeitusana Raus. — the Vil'va Lower Tournaisian limestones, and the overlying spheroidal limestones which correspond to the Malev level (Figure 2). The Vil'va limestones of the Endothyra communis and Quasiendothyra kobeitusana zone correspond to the first and second packets of the Dzhangan section. It should also be noted that, along with Endothyra communis and Quasiendothyra kobeitusana, the second packet of the section also contains brachipods of the Malev stratum — Camarotoechia panderi (S. et M.), etc. — and that the overlying (third) packet has goniatites of the Gattendorfia zone, thus causing some difficulties in correlating them with the Vil'va section.

The section through the boundary beds of

the Middle Pechora area, studied by A. V. Durkina [8], is shown in Figure 2. She marks that the beds with Septatournayella njumolga thus far have no analogs in the U. S. S. R. Nevertheless a partial analog is the second packet of the Dzhangana beds in the Berchogur trough, in which Ye. A. Reytlinger has found: Septatournayella njumolga Durk., S. potensa Durk, Quasiendothyra kobeitusana Raus. and Endothyra communis regularis Lip. Thus in its foraminifer composition the second Dzhangana packet corresponds, in the Middle Pechora section, to the beds with Endothyra communis and Quasiendothyra kobeitusana and the beds with Septatournayella njumolga and S. potensa, taken together. The occurrence in the Middle Pechora section of Chonetes aff. malevkensis Sok., Plicatifera ex gr. niger (Goss.) and Spirifer aff. tourncensis Kon. in the beds with Endothyra communis and Q. kobeitusana and, on the other hand, of Camaratoechia sp. (type panderi) and Spirifer ex gr. tourncensis Kon. in the beds with Septatournayella njumolga does not contradict their correlation with the second Dzhangana packet.

A certain discrepancy appears in correlating the deposits at the top of the sections being compared. In the Middle Pechora section the top of the Septatournayella njumolga beds is formed by spheroidal limestones assigned by A. V. Durkina to the undivided Malev and Upa levels, taken together. In the Berchogur trough the deposits of the second Dzhangana packet (containing S. njumolga and Endothyra communis regularis) are overlain by the goniatic limestone of the Gattendorfia zone. This higher stratigraphic position of the beds with Septatournayella njumolga and Endothyra communis regularis in the Southern Mugodzhary perhaps testifies to the later development of foraminifer assemblage in the Mugodzhary.

Thus according to the available data we are correlating the first (lower) packet of the Dzhangana section with the lower part of the Endothyra communis beds in the Middle Pechora section, taking account of the poverty of microfauna in the first packet of the Dzhangana deposits; the second Dzhangana packet is correlated with the remainder of the beds containing Endothyra communis and with the Septatournayella njumolga beds of this septip; the third (upper) packet of the Dzhangana section is tentatively correlated with the spheroidal limestones.

CONCLUSIONS

- In the section through the Famennian deposits of the Berchogur trough the following subdivisions have been distinguished: the Makarov, Murzakayev and Kurgandzhar beds.
- The Famennian deposits of the Berchogur

trough contain a brachiopod fauna closely linked in its composition with the fauna of the Makarov and Murzakayev beds on the western slopes of the Southern Urals, corresponding respectively to the Cheiloceras and Prolobites in the unified stratigraphic scheme adopted in 1951. In the deposits correlated with the Murzakayev beds on the western slopes of the Southern Urals there is a renewal of the fauna, especially in the development of the rhynchonellids, including the Chinese and Kazakhstan genus Yunnanellina Grabau.

3. The uppermost part of the section through the Famennian beds of the Berchogur trough contains the Kurgandzhar beds, characterized by a peculiar renewal of the brachiopod assemblage: representatives of the genus Camarotoechia H. et C. appear for the first time; the Kazakhstan species Pseudonudirostra plano-ovalis (Nal.) appears; and there are species very similar to those of the Lower Tournaisian — Camarotoechia intercalata sp. nov. (which closely resembles C. pleurodon Phill.), Pugnax biloba sp. nov. (which is close to P. acuminata (Mart.)), and others. The Kurgandzhar beds are correlated with the deposits of the Laevigites zone on the western slopes of the Southern Urals (according to the unified scheme of 1951).

4. The overwhelming majority of species of rhynchonellids that have been studied are guide fossils for the beds of the Famennian stage in the Mugodzhary area (Figure 2).

5. The beds that have been distinguished in the Famennian section may be traced on the margins of the Berchogur trough and in the central uplift, which excludes the subdivision of the Famennian deposits into a Berchogur (lower) stratum developed on the eastern margin, and a Karaganda (upper) stratum in the central uplift and the western margin (as is done in D. V. Nalivkin's scheme).

6. The distant relationship to the fauna of the Meysterov and sulcifer beds of Central and Northeastern Kazakhstan forces the author of this article to deny the validity of the beds of the same name in the Famennian deposits of the Berchogur trough.

7. The Lower Tournaisian deposits are characterized by a fauna differing sharply from the Upper Famennian, testifying to a single renewal of the fauna which occurs at the boundary between the Famennian and Tournaisian stages.

8. The fauna of the Lower Tournaisian Dzhangana beds resembles the fauna of the deposits of the same age on the western slopes of the Urals and in the Pechora area (Figure 2).

9. The section through the Dzhangana beds,

which conformably overlie the Upper Famennian deposits, contains (from bottom to top): a first and second packet, corresponding to the zone with Endothyra communis and Quasiendothyra kobeitusana (including the beds with Septatournayella njumalga Durk. in the Middle Pechora section) and a third packet (of goniatite limestones) belonging to the Gattendorfia zone.

10. The boundary between the Devonian and the Carboniferous in the Berchogur trough has been drawn by this writer at the bottom of the first (lower) packet of the Dzhangana beds, whereas Ye. A. Balashova [5] assigns the packet of goniatite limestones of the Gattendorfia zone (NCL) to the lowermost part of the Dzhangana formation.

In conclusion, the author wishes to express his deep gratitude to Ye. A. Reytlinger and B. I. Bogoslovskiy, who helped him greatly in the study of the microfauna and the goniatites, and also to V. V. Menner, V. N. Krestovnikov, and O. A. Lipina for their valuable advice and comment.

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Received, 29 February 1960

DIAMOND PROSPECTS IN THE CZECH MASSIF¹

by

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A dark-brown gem-quality pyrope, known as the "Czech garnet" throughout the world, has been mined for several centuries in a fertile agricultural region of northern Czechoslovakia, at the south slope of the Czech Middle Highlands (a volcanic region of Tertiary alkalic extrusives. First, it was picked up directly in tilled fields; later on, it was mined by primitive means from Quaternary deposits, the so-called "garnet gravels", in two localities. Garnet was found in "conglomerates", either cropping out in hills or buried. In Lingorka Hill, near the village of Tršebenice, and in Garnet Hill (Bota), at Merunice (Figure 1), pyropes were mined in these "conglomerates" by means of shafts, at a depth of 60 m. The volcanic origin of these rocks was, at that time, unknown.

In 1869, a diamond was accidentally found along with garnets (Figure 2). Its dimensions were 4.13 x 2.63 mm, weight 0.057 gm (specific gravity, 3.483); color, yellow; form, irregular with a corroded surface showing octahedral faces with triangular nicks. Another diamond crystal was found in 1927, a colorless octahedron, about 2 mm, with thin foliated triangular faces and a zoned striation of the edges (Figure 3). The two findings have been described by B. Jezek [9, 10]; they are stored in the mineralogic section of the Prague National Museum.

By the turn of the century, C. Zahalka [16], and J. E. Hirsch [8] after him, established the presence of many minerals in the "garnet pebble beds": diamond, corundum (ruby and sapphire), zircon, hyacinth, limonite, ilmenite, red and black spinel (pleonaste), olivine, bronzite, augite, amphibole, disthene, topaz, tourmaline, common garnet, pyrope, and beryl (also found recently were chrome-spinel and chrome-diopside).

It has been subsequently determined that the "garnet conglomerates" are volcanic breccia in a vertical column, cutting the enclosing

Cretaceous deposits; their petrographic composition, however, remained obscure. J. E. Hirsch, who made a detailed study of volcanic rocks in the Czech Middle Highlands, termed them basalt breccias in 1920, although F. Slavik [13] pointed out that the first diamond found has been associated with pyrope, as is the case in South African diamond mines. It should be kept in mind that Hirsch's specimens were highly weathered, having been dug out of exposed garnet-bearing breccias.

In 1958, the Central Geological Institute of Prague was informed by the All-Union Geological Institute (VSEGEI, Leningrad) that P. N. Mikhaylov, a scientist at the Institute, had pointed out, after studying Czech references [14], the presence in Czechoslovakia of pyrope-bearing volcanic rock bodies reminiscent of Siberian kimberlite pipes in form.

That prompted us to resume the study of pyrope-bearing rocks in the Czech Middle Highlands.

GEOLOGIC STRUCTURE OF CZECHOSLOVAKIA AND THE FORMATION CONDITIONS OF KIMBERLITES

Czechoslovakia occupies a part of the Czech crystalline massif which was consolidated in the late Paleozoic, in Middle Europe (Figure 4). During the Hercinian folding, geologically isolated bodies formed a discrete cratonic block here; at the close of the Paleozoic and Mesozoic, lacustrine and epicontinental deposits were laid down in patches, along the periphery and in the middle of the massif, which suggests isostatic movements of that block. Formed over the area of the massif were Carboniferous basins, thick Permian deposits with melaphyre intrusions and extrusions, and then a Meso-Cenozoic trough which inherited the basic tectonic lines of the Czech Massif core. This trough was formed by what was left of the Triassic deposits, and of Jurassic deposits in the northeast; it is filled largely with Upper Cretaceous and Neogene deposits and with thick beds of brown coal in the northwest.

¹Ob al'mazonosnosti Cheskogo massiva.

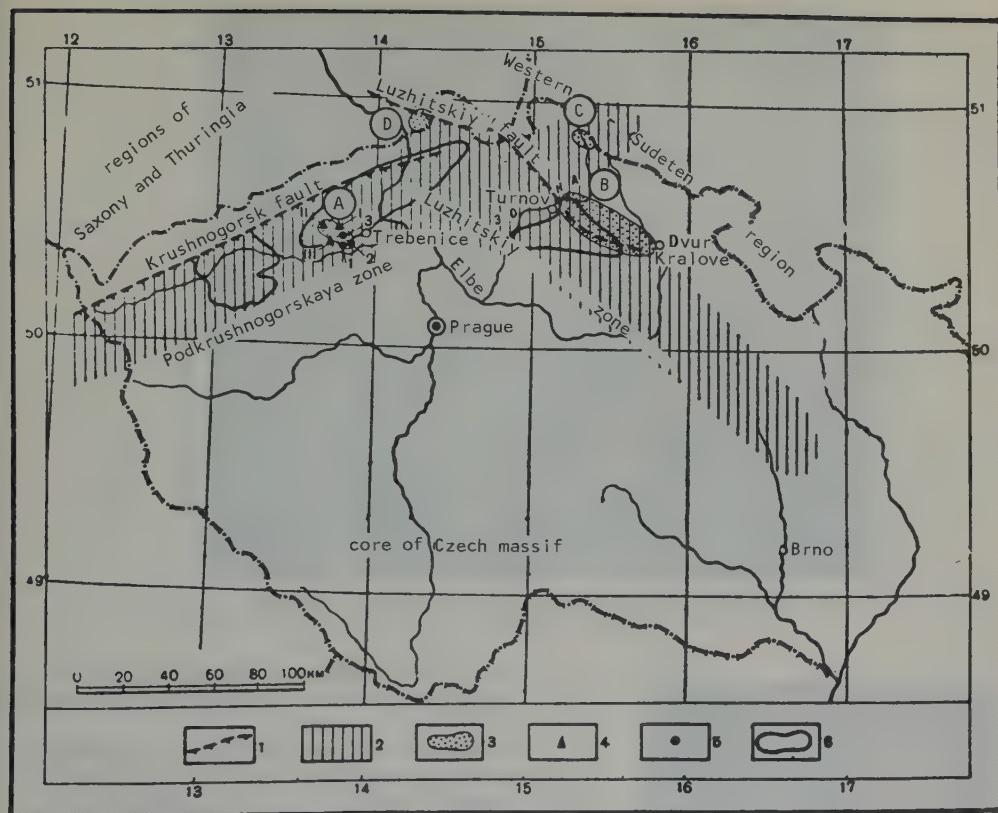


FIGURE 1. Sketch map showing the tectonic structure of the Czech massif:

1 - tectonic faults; 2 - tectonic zones; 3 - Quaternary deposits containing heavy mineral associations accompanying diamonds: A - Czech hills; B - Northeastern hills; C - Jizer meadows; D - Seifengründel; 4 - locations of kimberlite within the Czech hills; I - Lingorka, near Trebenice, II - Granatovyy verkh and a new pipe near the village of Merunice, III - Velikiy and Malyy verkh, near Trtens; 5 - places where diamonds have been discovered; 1 - first (1869), 2 - second (1927), 3 - third (1959); 6 - distribution of Tertiary volcanics in Czechoslovakia.

In the central and oldest part, the so-called core of the Czech Massif, these deposits (post-Caledonian) are of a platform type; they were not folded but deformed by vertical movements. For this reason, the structure of the Czech Massif and especially its core are reminiscent of a shield, comparable to the Precambrian Siberian, African, and other shields, which is what has determined the formation of kimberlites.

The Czech Massif may be divided on the whole into three non-contemporaneous provinces (Figure 1).

1. The core (particularly the platform province) is the southernmost and the oldest segment of the massif. It is made up of Precambrian metamorphics overlain in the south by Cambrian and Paleozoic non-metamorphosed rocks affected by Hercinian folding; in the north it is overlain by Upper Paleozoic and Mesozoic and Cenozoic platform deposits.

2. West Sudeten province (caledonids) is the northeastern and younger segment of the Czech Massif.

3. The Saxon-Thuringian province (hercينids) is its northwestern segment, apparently the youngest, formed during Hercinian folding.

These provinces are defined by tectonic contacts. The pyrope province of the Czech Midland Highlands is associated with places where a still imperfectly known tectonic boundary between the old Precambrian core of the Massif and its younger Saxon-Thuringian segment passes through metamorphic rocks, at the base of Cretaceous and partly of Permian platform deposits.

According to Soviet students, kimberlites are associated with such major tectonic zones.

Finally, associated with the two major



FIGURE 2. First diamond found in Czechoslovakia. Natural size, 4.13×2.63 mm



FIGURE 3. Second diamond found in Czechoslovakia. Natural size about 2 mm

tectonic zones along which the Czech Massif core is in contact with the younger structures, is a differentiated alkaline volcanism, which also suggests the presence of kimberlite in the Czech Massif.

THE STUDY

First of all, the authenticity of the original diamond findings had to be ascertained, a subject of controversy between Czech and German mineralogists. Our students maintained that both diamonds had been formed in the Czech Massifs, while the Germans claimed that the

first diamond had been imported to Czechoslovakia accidentally and perhaps intentionally.

With this in mind, we had to determine the origin of pyrope as a diamond associate, the geologic conditions of its formation and its petrographic composition, as well as the manner of distribution of pyrope-bearing rocks.

In 1958-1959, we carried on geologic mapping and drilling, along with beneficiation work, to determine the heavy mineral content.

Our task was made easier by the works of Soviet geologists, particularly "Diamonds of Siberia" (1957); a Russian translation of "The Geology of South Africa" [1]; and the works of V. S. Naumov and G. V. Trofimov [4] and A. P. Burov (1958). We also used P. A. Wagner's book [15] on kimberlites of South America. Of great value was the assistance of the All-Union Geological Institute which sent us a large collection of western Yakutian kimberlites.

The geologic mapping made it possible to determine in detail the form of the volcanic bodies, specifically the pyrope-bearing volcanic breccias, whose area had been considerably exaggerated in all earlier maps. It turned out that the outcrops of these breccias were volcanic pipes, irregularly round to elliptical in section as a rule; these pipes are of considerable size and pierce the sedimentary rocks. In this respect, they are similar to kimberlite pipes of Siberia and South Africa (Figure 5).

Having opened an old shaft, formerly used in the mining of pyrope in the west slope of the Lingorka Hill of volcanic breccia, we ascertained

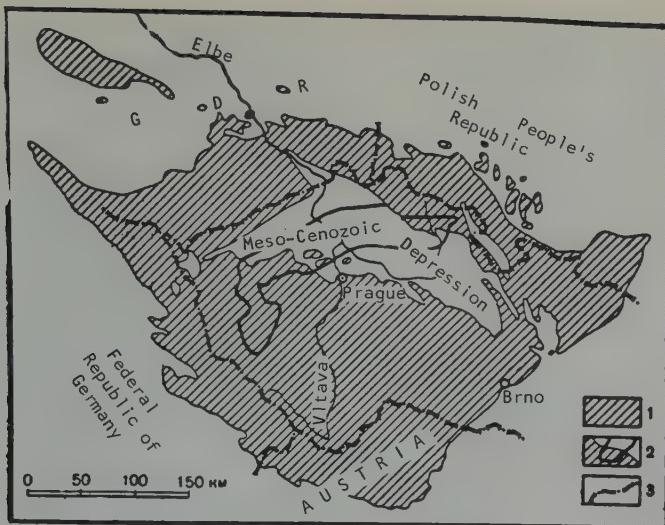


FIGURE 4. Sketch map:

1 - crystalline rocks of the Czech massif; 2 - Upper Paleozoic deposits (Carboniferous-Permian); 3 - state's boundaries

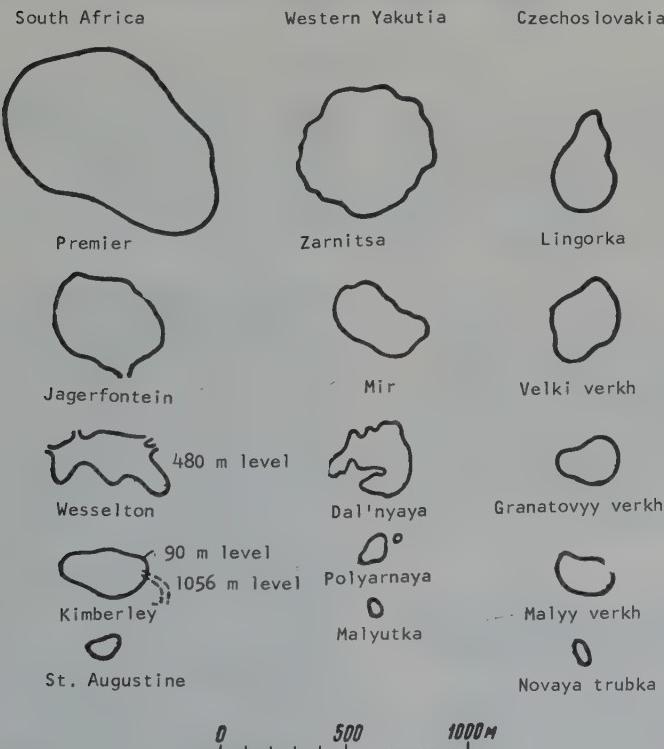


FIGURE 5. Comparison of the shapes and sizes of pyrope-bearing volcanic breccia bodies (kimberlite breccias) of the Czech hills with the kimberlites of Siberia and South Africa (comparison cited from V.S. Trofimov).

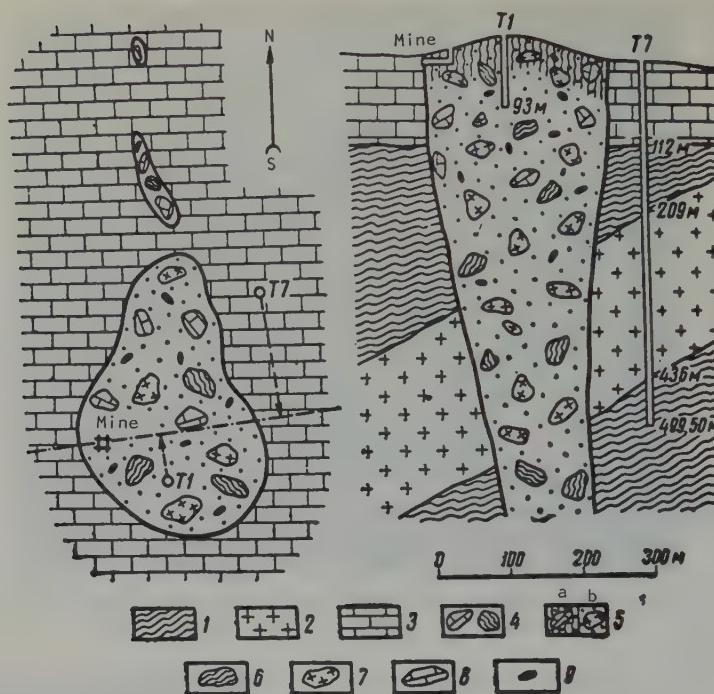


FIGURE 6. Sketch map and diagrammatic section through the Lingorka kimberlite pipe:

1 - granulite, gneiss, migmatite; 2 - serpentized pyroxenite pyrope peridotite; 3 - Upper Cretaceous; 4 - volcanic breccia without pyrope; 5 - pyrope-bearing volcanic (kimberlite) breccia; a - weathered, b - unweathered, carbonized; 6 - xenoliths of granulite gneiss and migmatite; 7 - xenoliths of serpentized pyroxene pyrope peridotite; 8 - xenoliths of Upper Cretaceous deposits; 9 - xenoliths of Tertiary rocks composed of ooze with carbonized wood.

that these bodies continue deeper. A drift cut from the bottom of the shaft toward the edge of the volcanic body, as far as the host rocks of Cretaceous age, crossed a cylindrical body of pyrope-bearing volcanic breccia, passing vertically through older rocks (Figure 6). The drilling revealed an extension of the body, down to 93 m. Like the South African kimberlites, these rocks were deeply weathered (to 40 m), with unweathered deeper reaches being carbonatized.

The origin of xenoliths of serpentized pyropic pyroxene peridotite, encountered in the mining of garnets (Figures 7, and 8), along with fragments of gneiss, granulite, and of the Cretaceous and Tertiary rocks, was determined by drilling a structural test T-7, about 80 m east of the pipe (Figure 6). The test penetrated 112 m of horizontal Upper Cretaceous beds; from there down to 209 m, it drilled in granulite changing to gneiss; a thick intrusive body of serpentized pyropic pyroxenite was encountered at 227 m; and the test stopped at 499.5 m, once more in granulitic rocks.

In 1958, I discovered another pyrope-bearing pipe, almost completely covered by two meters of chernozem (black loam), in the vicinity of Merunice, 150 m southwest of the Granatny Verkh (Figure 8). This important fact suggests a similarity of that pyrope-bearing pipe to African and Siberian kimberlites which, too, are not exposed; this also gives reason to assume the presence of other kimberlite pipes. The drilling of test T-11 convinced us that the pyrope-bearing rock continues deeper. Rocks near the surface were so weathered that they looked more like tuffite than volcanic breccia.

Heavy minerals obtained from the fragmented material at a pipe discovered in 1958 were studied at the VSEGEI, under the direction of N. S. Alimov. An analysis by N. P. Mikhaylov (VSEGEI) revealed that they were indeed kimberlite (kimberlite breccias). Heavy minerals identified included pyrope (red, orange, and lavender), ilmenite, dark-green monoclinic pyroxene, grossularite, chrome spinel, rutile, zircon, pyrite, apatite, topaz, tourmaline, and limonite. The author expresses his deep gratitude to the VSEGEI personnel.

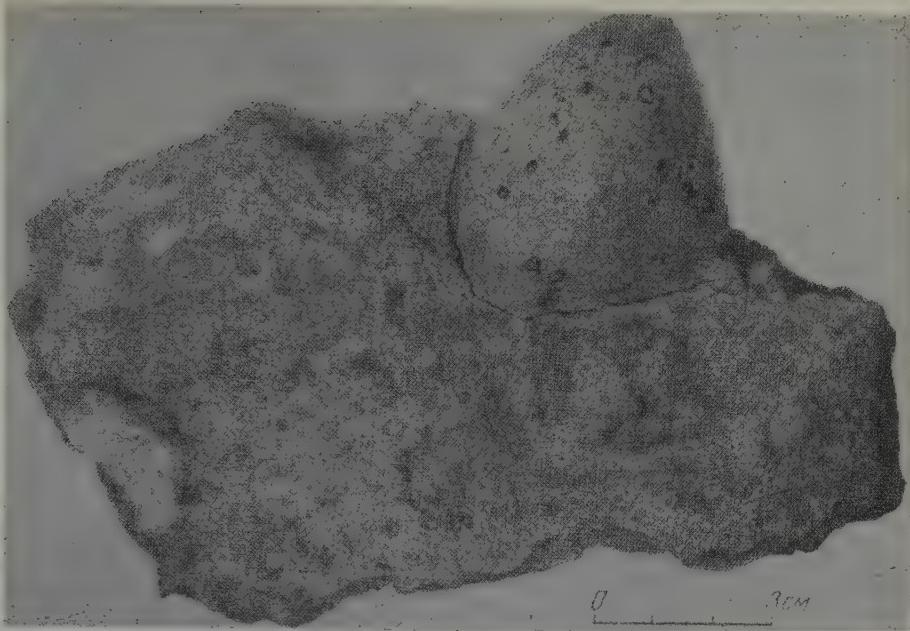


FIGURE 7. Xenolith of serpentized pyroxenic pyrope peridotite in the weathered kimberlite breccia of Lingorka, from the mine on the western slopes of the hill.

Further study revealed pyrope deposits of diverse genetic types. In 1958, we found Upper Cretaceous (Cenomanian) pyrope-bearing sandstones among xenoliths in the "Velikiy Verkh" kimberlite pipe, near the village of Tršten (Figure 1). Even more interesting pyrope-bearing tuffites were discovered toward the end of 1959 at the foot of the northwestern slope of the Sviný Hill, near Merunice. These tuffites carry zircon, corundum (sapphire), and green monoclinic pyroxene. The presence of these rocks, occurring among Cretaceous deposits and on basalts, suggest the proximity of another undiscovered kimberlite body.

It is also of importance that J. Bauer (Mineralogical Section of the Prague Chemical and Technological Institute) has found a diamond (a transparent octahedron, 0.3 mm in diameter [9]) in the Czech Middle Highlands area.

According to J. Kourjimsky (Prague National Museum, 1959), the diamond found in Czechoslovakia differs from foreign diamonds (with the exception of Siberian types) in its yellow-orange color. This indicates that diamonds found here are indeed native.

Thus the kimberlite nature of the Czech pyrope-bearing volcanic breccias has been demonstrated, and there is every reason for assigning the three native diamonds to a kimberlite magma rather than to xenoliths of "pyrope serpentine" as has been done up to now. Such an origin for the Czech Middle Highlands

pyrope has also been corroborated by M. Kralova's chemical analyses (Prague Chemical and Technological Institute, 1958). These analyses have shown that pyrope is formed not only in the pyrope peridotite cut by kimberlites but apparently also in the kimberlite magma itself. We believe it of great significance that R. Post (Prague University) has discovered chrome diopside, an associate of diamond, in the "pyrope gravels".

The course of further exploration is charted by geophysical results. The 1959 determination of magnetic susceptibility of samples of kimberlite breccia from the new pipe near Merunice has demonstrated the feasibility of using magnetometry in the search for kimberlite bodies, while the 1959 gravimetric measurements by the Geological Survey have made it possible to trace deep ultrabasic rocks closely associated with kimberlite.

Soviet geologists have never failed in their practical assistance in organizing and conducting this field work.

We have obtained valuable advice from I. S. Rozhkov (Chairman of the Presidium for the Yakutian Affiliate, U. S. S. R. Academy of Sciences). In the fall of 1958, he participated in a field trip to study pyrope gravels of the Czech Middle Highlands. He, too, assigned the origin of the Lingorka breccia to kimberlites and voiced his opinion on the possibility of finding diamond-bearing kimberlites in

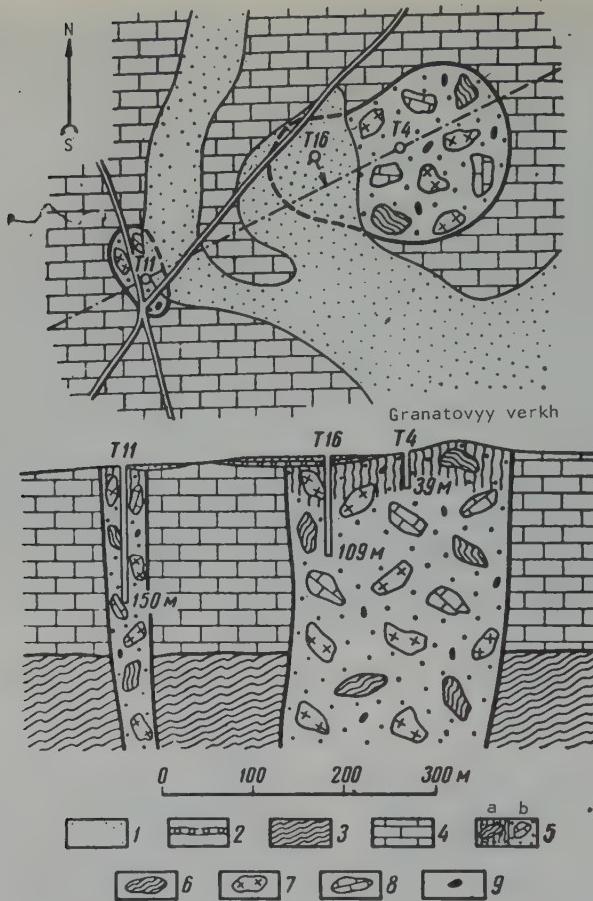


FIGURE 8. Suggested geologic section through the morphologically undetermined kimberlite pipe and the kimberlite of Granatovyy verkh near the village of Merunice:

1 - chernozem, loess; 2 - pyrope-bearing gravel with ooze; 3 - granulite, migmatite; 4 - Upper Cretaceous; 5 - kimberlite breccia: a - weathered, b - unweathered and highly carbonatized; 6 - xenoliths of granulite; 7 - xenoliths of serpentinitized and for the most part also opalized pyroxene pyrope peridotite; 8 - xenoliths of Upper Cretaceous deposits (chiefly marl and limestone); 9 - xenoliths of Tertiary porcellanite.

Czechoslovakia. He read an interesting paper on diamond prospecting in the Siberian platform, before the Mineralogy Section of the Prague Chemical and Technological Institute.

Soviet Geologist V. O. Ruzhitskiy paid us a visit in 1959. He spoke on his work on the occurrence of diamonds and gave valuable advice on diamond exploration [3]. We were especially interested in his views on the second pyrope and diamond province of the Russian platform with its Precambrian crystallines of the Ukrainian shield. Basalt and dolerite, probably Tertiary in age, as well as older diabase and porphyrite

are believed to be exposed there. Three microscopic diamond crystals have been found in a basalt rock of Czechoslovakia, near the village of Berestovets.

This second pyrope province is similar to the Czech Middle Highlands. Here, between Turnov and Dvur Kralove mountains of northeastern Czechoslovakia, pyrope occurs in association with ilmenite, spinel, and olivine, in a band of Quaternary deposits about 15 km wide. Also occurring here, according to published data, are occasional fragments of Cretaceous sandstone with pyrope; there is a finding of

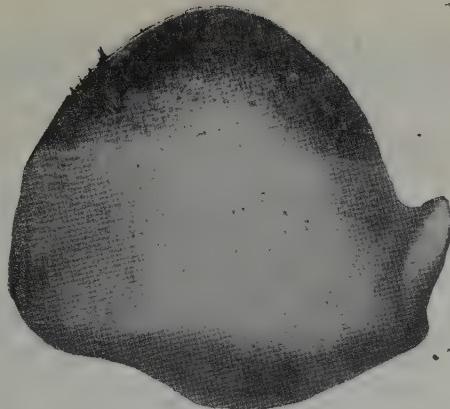


FIGURE 9. Third discovery of a
Czechoslovakia diamond.
Natural size 0.3 mm. ~



FIGURE 10. Columnar sculpturing
of the surface of a grain of red
pyrope from Quaternary deposits
in the area of the village of
Kye (northeastern Czechoslovakia)
Natural size 2 mm.



FIGURE 11. Conchoidal sculpturing
of the surface of a grain of violet-
pinkish garnet from Quaternary
deposits in the vicinity of the
village of Kye in northeastern
Czechoslovakia. Natural size
1.5 mm.

eruptive (?) rock, believed to be basalt, and carrying pyrope grains (evidently a pyrope-bearing serpentine rock). In the current year, J. Bauer and the author, working in the alluvium and in higher terrace deposits, identified almost all of the minerals associated with diamond: pyrope, ilmenite, phlogopite, less common monoclinic pyroxene (probably chrome diopside), along with other minerals typical of kimberlite: spinelids, zircon, magnetite and assorted garnets. Especially significant are pyropes of various colors, common in kimberlite (light to dark red, yellow, orange, lavender). These pyropes (especially the red and rose-lavender types) have rough surfaces, probably as a result of magmatic corrosion (Figures 10 and 11). The same phenomena are described in "Diamond Occurrences in Yakutia", recently published in the U.S.S.R.

Associations of heavy minerals in different localities of that province differ from one another, having come apparently from different sources. It is possible, then, that undiscovered kimberlite pipes, associated with Tertiary alkalic volcanism, may be present in the pyrope area of northeastern Czechoslovakia.

CONCLUSIONS

1. The data extant on pyrope-bearing ultrabasic rocks of the Czech Massif reveal their great similarity to diamond provinces of a platform type, the Siberian and African shield as well as the Russian platform and its western margin, the Ukrainian shield, where, according to V.O. Ruzhitskiy [3], several diamonds have also been found.

2. In the Czech Massif area, the findings of diamonds and associated minerals are confined to provinces marked by a comparatively shallow occurrence of the ancient (Precambrian) crystalline platform covered by undisturbed sediments. The latter are cut by alkalic extrusive rocks. Among these provinces are the Czech Middle Highlands of northeastern Czechoslovakia where, judging from the presence of heavy minerals in unconsolidated Quaternary sediments, kimberlite bodies may occur.

It is also known that an association of heavy minerals common in kimberlites occurs in Quaternary deposits of the so-called Jizer Meadows (northeastern Czechoslovakia) and in the Seifengrindel area near Hinterhermsdorf (East Germany). These two localities fall in the projection of tectonic zones of the two principal pyrope provinces of Czechoslovakia.

The heavy fraction of the Jizer Meadows deposits contains magnetite, titano-magnetite, pi-croilmenite (with 7 to 8% Mg), zircon (hyacinth), corundum (sapphire), spinelids, garnet (essonite), green tourmaline, and olivine (?).

Present in the Seifengrindel area are magnetite, ilmenite, zircon (hyacinth), corundum (ruby), spinelids (specifically, ceylonite), olivine, amphibole (basaltic), augite, garnet (auriferous), rutile, bronzite, green diopside, and apatite.

Basaltic eruptive rocks (olivine nephelinites) with ilmenite are exposed in the vicinity of these localities.

3. Magmatic olivine schlieren occur only as an exception in basalts of the Czech Middle Highlands (reaction fringe at the basalt contact). Their high Ni and Cr content, along with the presence of chrome diopside [7], suggest their xenolithic nature and the presence of ultrabasic intrusions deeper in the basement; this is of importance in our exploration. In their chemical and mineralogic composition, these olivine bodies are reminiscent of the kimberlite xenoliths.

4. According to South African students [1], there is a close geologic connection between kimberlites and basic alkalic extrusives carrying nepheline — olivine nephelinites. Kimberlites belong to the alkalic rock group. In the opinion of G.S. Lewis and M.S. Tallard (cited by S.J. Shand, [12]), kimberlite is a strongly altered olivine melilitite, while nepheline accompanies the primary rock-forming minerals [15] containing — along with olivine, ilmenite, and pyrope — phlogopite, melilite, and perovskite. Out of these, olivine, nepheline, melilite, and perovskite are the principal rock-forming minerals in alkalic rocks of Czechoslovakia: polzenites and their associates.

5. Principal tectonic zones of the Czech Massif are characterized by upper Paleozoic (metaphyre) and Neogene (basalt) volcanics.

6. The positive gravity anomalies along the south margin of the Czech Middle Highlands, in the vicinity of kimberlites, may be explained by the presence of vein-like bodies of intrusive basic rocks, as is the case in the eastern Baltic and in the peripheral parts of the Anabar shields [3]. In analogy, the presence of ultrabasic intrusive rocks may be assumed also for pyrope-bearing deposits of northeastern Czechoslovakia where several peridotite veins have already been discovered.

7. We believe that the pyrope provinces of Czechoslovakia offer suitable prospects for a further exploration for diamonds.

Platform provinces are known to be most favorable for prospecting for kimberlites and other intrusive ultrabasic rocks; this is especially true for those localities where major tectonic zones occur and intersect. The Czech Massif core and adjacent areas are just such places in Czechoslovakia.

In this connection, we deem it expedient to explore the areas of the Podkrushnogorsk and Lujick tectonic zones.

Occurring at the intersection of these zones are melilite-bearing ultrabasic vein rocks of the polzenite type, similar to kimberlites in composition; also volcanic pipes filled up with breccia carrying ilmenite, olivine (chrysolite), and green monoclinic pyroxene.

An important part in our exploration will be played by geophysics and especially by magnetometry.

Extensive beneficiation will have to be carried out in determining the presence of diamonds in unconsolidated pyrope-bearing rocks and in kimberlites. This work is scheduled for the current year.

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Received, 10 May 1960

ALKALIC INTRUSIVES IN THE MARITIME PROVINCE¹

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Alkalic igneous rocks were discovered by A. P. Karpinskiy, in the Iman River basin, as early as 1897. Later on, alkalic basaltoid lavas of northeastern Manchuria were described by A. Lacroix, in 1930.

In 1950, G. A. Gapeyeva studied alkalic basaltoids in a transition zone from the Ussuri plain to the Sikhote-Alin foothills, while A. T. Oktyabr'skiy studied them in the Artem-Tavrichansk trough. According to F. A. Gapeyeva, these rocks cut a Precambrian crystalline body as well as Pliocene gravel beds, and form small isometric to elongated bodies, as much as 120 m across.

According to A. T. Oktyabr'skiy, the Artem-Tavrichansk trough alkalic igneous rocks cut Tertiary deposits and Pliocene gravel beds. They are represented by alkalic dolerite and leucitic basalt types forming small stocks, laccolithic interformational bodies, and dikes.

Nepheline syenite were first identified in the Maritime Province (1.5 km southwest of Koskharevka village), by N. A. Belyayevskiy, N. G. Belyayevskaya and G. P. Tolmachev, in 1953. However, outcrops of these rocks were discovered as recently as 1959, by geologists of the Maritime Geological Administration.

On the basis of her own and other published data, G. A. Gapeyeva identified (1953) an alkalic province in the western maritime region, represented by granitoids (aegirine granite and aegirine nepheline syenite) and basaltoid varieties (trachydolerite, basanite, nepheline and leucite basalt, leucitite, limburgite, ankaramite-picrite, etc.).

Alkalic intrusives represented by nepheline and alkaline syenites are also known from the north part of Sakhalin and were described by V. M. Fon Derviz as early as 1915. According to her, nepheline and alkalic syenites occur on the west coast of Sakhalin (south of Aleksandrovsk) where they form dikes, up to 30 m

thick, cutting Cretaceous conglomerates. Nepheline syenites are associated with large sub-meridional zones of faulting.

According to the same author [6] extrusive alkalic rocks of the tephrite group, associated with the youngest deformations that preceded the post-Pliocene transgressions occur in northern Sakhalin.

In the Morotu area, south Sakhalin, K. Yagi [10] discovered intrusive alkalic syenites and monzonites, in 1944, and described them in 1953. He also pointed out that alkalic basaltoids are widely developed in Japan.

Thus, it appears that alkalic igneous rocks are more common in the Maritime Province and the southern Far East, than has been assumed (Figure 1). The data on hand make it possible to divide these rocks into two large groups. To the first group, better called sub-alkalic, we assign alkalic granites, quartz syenites, and syenites associated with granite and usually terminating the complex granitoid intrusions. These rocks are of different ages and occur in the Maritime Province in different structural-facies zones.

The second group includes nepheline syenite of the foyaite type, tinguaite, and other varieties, associated spatially, and probably genetically, with ultrabasic rocks. These rocks are related to zones of deep faults and their associated plume fractures, more specifically with the central Sikhote-Alin fault (Figure 2). These rocks are late Mesozoic to Tertiary in age, with no older ones yet known.

Associated with nepheline syenite and tinguaite are carbonate rocks, similar to carbonatites in mineral composition.

This paper describes briefly the nepheline-bearing intrusive rocks of the second group and their associated post-magmatic formations. We studied these rocks in 1959, in the basins of Ulahe and Fudzin Rivers. They are represented here by tinguaite and by foyaite-type nepheline syenite, whose dikes and small stocks cut the pyroxenite.

¹O shchelochnykh intruzivnykh porodakh primor'ya.

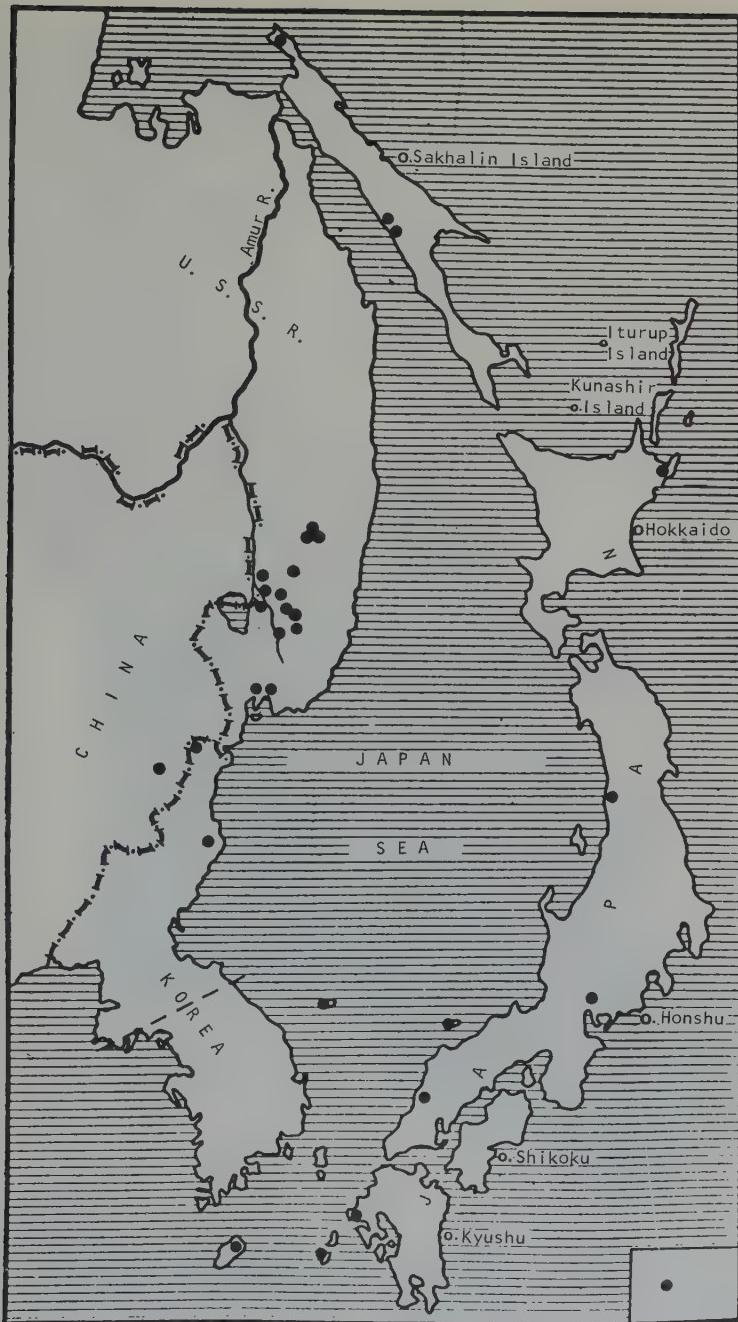


FIGURE 1. General map showing the distribution of alkalic rocks in the Primor'ye, Sakhalin and Japan.

The black dots indicate outcrops of alkalic rocks.

Pyroxenites of this area, as well as other ultrabasic rocks occurring in the same fault zone, in basins of the Kafe, Katen, Sukpay, and other rivers, form minor stock-like and

dike-like bodies, from a few tens of meters to 12 km long, and up to 2 km wide. In the middle course of the Kefa, ultrabasic rocks cut and alter Lower Cretaceous sedimentary rocks.

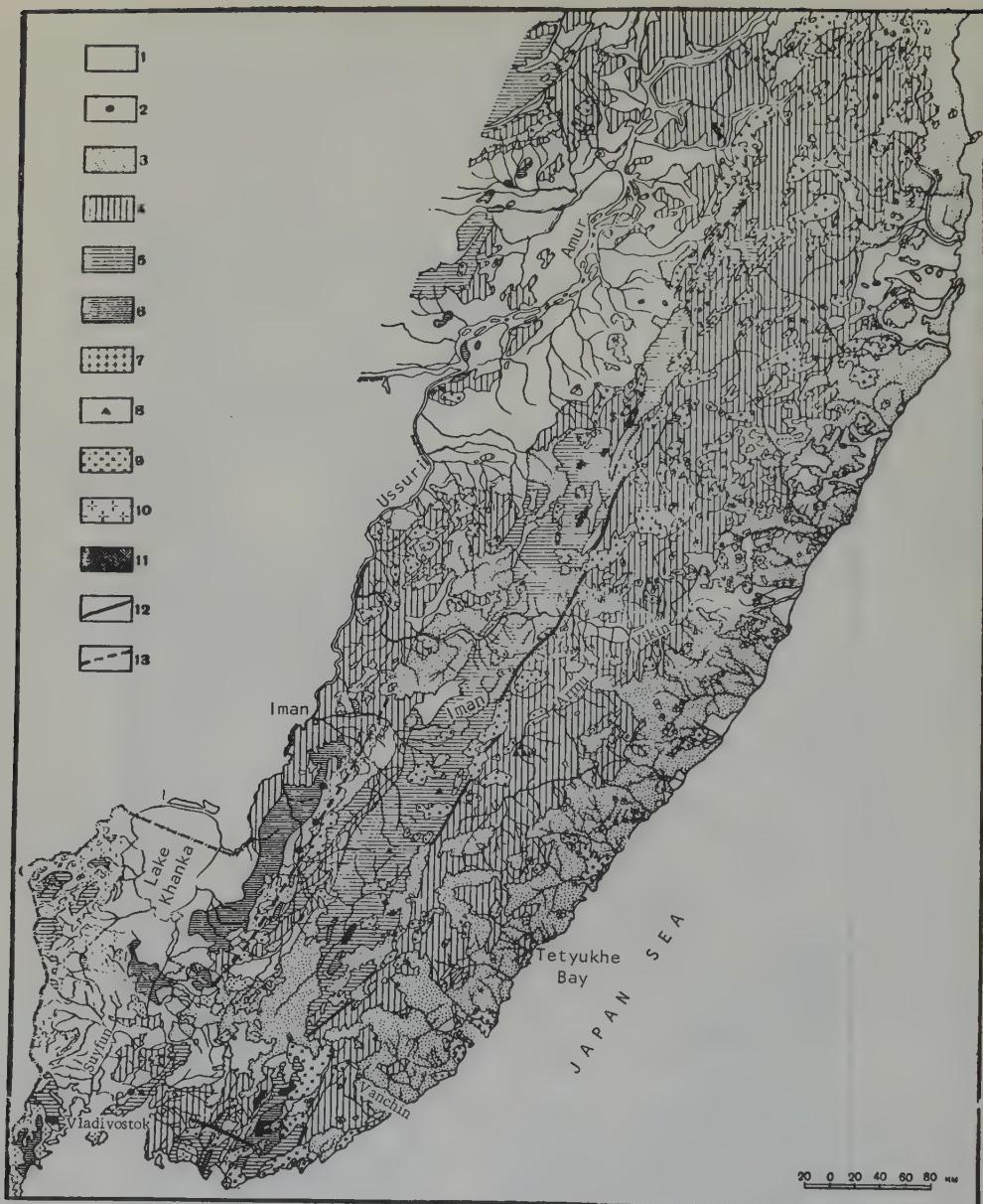


FIGURE 2. Map showing the distribution of igneous rocks of various ages in the Sikhote-Alin and Prikhankay region:

1 - post-ore formation consisting of Pliocene basalt, Eocene-Oligocene coal-bearing deposits and unconsolidated deposits of the Suyfinskaya suite; 2 - alkalic extrusives and subvolcanic rocks; 3 - Upper Cretaceous and Tertiary extrusives; 4 - sedimentary rocks of Mesozoic age; 5 - sedimentary rocks of late Paleozoic age and subordinate extrusives; 6 - rocks of an early Paleozoic and Precambrian complex; 7 - Tertiary granitoids; 8 - Late Cretaceous nepheline syenite, tinguaiite, alkalic syenite and other varieties of alkalic rocks; 9 - Late Cretaceous and Jurassic granitoids; 10 - Paleozoic granitoids; 11 - basic and ultra-basic rocks, mainly of Late Cretaceous age; 12 - central structural suture of Sikhote-Alin; 13 - western structural suture.

The minimum age of these intrusives has not been established; they have been assigned conditionally to the Upper Cretaceous.

The Ulahe basin pyroxenites consist of titaniferous augite (80 to 85%, brown in sections, occasionally with a red or violet tint; $\gamma = 46$ to 48; $2V = 56$ to 60°); apatite (2 to 6%), and titanomagnetite (6 to 18%). Their structure is panidiomorphic-granular, locally sideronitic, because of titanomagnetite cementing the pyroxene crystals. Two generations of apatite are present; the first is represented by elongated prismatic crystals (from a few hundredths to 1 mm), clearly idiomorphic with the titanomagnetite and titaniferous augite; the second is represented usually by short columnar crystals, more commonly by irregular grains (0.1 to 2 mm) which fill up interstices between the titaniferous augite grains. The relationship between second generation apatite and titanomagnetite is different in different sectors: apatite occurs in titanomagnetite either as idiomorphic crystals or in interstices (Figure 3). It is probable that

variety. Semi-quantitative spectrographic analysis of apatite established the presence (in %) of Sr, 0.1; P \pm n; F = n; Zr, 0.003 to 0.006; Y, 0.03 to 0.06; and La and Ce, 0.1. Only copper was identified among the metals (0.003%), with the iron group represented by Ti, 0.03%; Mn, 0.01%; and V, 0.003%.

Of particular interest is the presence in this apatite of yttrium and rare earths, typical of the second group of alkalic rocks and of carbonatites. Spectrographic analysis of titanomagnetite has revealed, besides a large amount of Fe and Ti, the presence (in %) of Sr, 0.03 - 0.06; Ga, 0.003; Zn, 0.03 to 0.06; Cu, 0.003; Mn, 0.1 to 0.3; V, 0.01 to 0.03; and Cr, Co, Ni, 0.003.

Sphene and pyrite have also been identified in synthetic concentrates of pyroxenites. Post-magmatic processes in the latter are expressed by a replacement of titaniferous augite by alkalic hornblende, and of the latter by vermiculite. A chemical analysis of pyroxenites is given in Table 1.



FIGURE 3. Tinguaite, general view. Porphyritic segregations of nepheline (H), potassium feldspar (K) and aegirine (black) are surrounded by a fine-grained ground mass consisting of albite, orthoclase and aegirine.

Thin section 1886: magnification 16, crossed nicols.

crystallization of apatite began prior to and ended after the formation of titanomagnetite. Refractive indices for apatite, determined by the immersion method, are as follows: $\gamma = 1.640 \pm 0.002$; $\alpha = 1.636 \pm 0.002$.

In synthetic concentrates, apatite is present in large amounts in the heavy non-electromagnetic fraction, as hexagonal prisms and irregular grains. In rocks under study, orange apatite grains² occur together with the colorless

In addition to these augite-pyroxenites, G. P. Tolmachev and N. G. Belyayevskaya identified in the Ulahe basin (Lampaheze, Kaluzhika rapids, etc.) avezacites (amphibole pyroxenites) and teschenites. Avezacites consist largely of brown hornblende, augite, magnetite (or titanomagnetite), apatite, and sphene. Teschenites contain, besides those minerals, plagioclase and analcite.

A chemical analysis of avezacite, after G. P. Tolmachev, is given in Table 1. It shows a great similarity between avezacite and pyroxenite (sample 1901), with the avezacite carrying somewhat more TiO_2 , MgO , and FeO , and correspondingly less Fe_2O_3 , Al_2O_3 , and

² The orange coloration is due to the presence of iron hydroxides (the color disappears in acid).

Table 1

Results of Chemical Analyses of Pyroxenites

Oxides	Pyroxenite		Avekazite (amphibole pyroxenite)	Oxides	Pyroxenites		Avekazite (amphibole pyroxenite)
	sample 1901	sample 1908			sample 1901	sample 1908	
SiO ₂	33.21	—	34.36	Figures taken from A. N. Zavaritskiy			
TiO ₂	2.15	—	5.24	<i>a</i>	2.2	0.7	
Al ₂ O ₃	11.30	—	7.22	<i>c</i>	6.5	4.3	
Fe ₂ O ₃	17.78	—	13.21	<i>s</i>	52.0	53.3	
FeO	7.94	—	11.84	<i>S</i>	39.3	41.7	
MnO	0.24	—	0.20	<i>f'</i>	44.2	40.9	
MgO	8.82	—	11.66	<i>t</i>	4.6	10.2	
CaO	16.88	—	14.60	<i>φ</i>	34.3	20.3	
K ₂ O	0.12	0.25	—	<i>n</i>	94.0	60.0	
Na ₂ O	0.92	1.08	—	<i>a'</i>	—	—	
H ₂ O-	0.30	—	0.50	<i>Q</i>	32.3	—22.3	
H ₂ O ⁺	0.45	—	1.41	<i>c'</i>	27.1	23.8	
P ₂ O ₅	not analyzed	—	not analyzed	<i>a</i>	0.3	0.2	
CO ₂	0.40	—	—	<i>c</i>	28.7	35.3	
Total	100.57		100.64				

Samples 1901 and 1908 were analyzed from our materials in the chemical laboratory of I. G. E. M. of the Academy of Sciences of the U.S.S.R. by analysts V.I. Klitina and L.M. Krutitskaya. The chemical analysis of the avekazite was taken from G.P. Tolmachev and N.G. Belyayevskaya.

alkalies. This difference is probably due to a lower titanomagnetite content in avekazite, the lack of mica, and a higher sphene content.

The pyroxenites under study are cut by tinguaite dikes, from 50 cm to 10 m thick, and by small stock-like bodies of nepheline syenite (foyaite type). They trend to the northeast, less commonly to the northwest, and make sharp contacts with the pyroxenite. In some localities, a corrosion of augite by hornblende has been observed in pyroxenite in direct contact with the dikes. The altered pyroxenites range in thickness from 2 to 10 cm, depending on the thickness of the tinguaite dikes. Vermiculite is present in the pyroxenites in the vicinity of tinguaite and nepheline dikes. In the Fudzin basin, pyroxenites form a fracture intrusion associated with the core of an anticlinal fold trending N - 40° - E.

These rocks are probably Upper Cretaceous or Lower Tertiary because they cut Upper Cretaceous pyroxenite and Senonian porphyrite, and are overlain by tuffite and tuffaceous sandstone with a Danian-Paleogene fauna.

Macroscopically, tinguaites are fine-grained gray rocks consisting of nepheline ($\gamma = 1.540 \pm$

0.002, $\alpha = 1.536 \pm 0.002$, as determined by the immersion method), K-feldspar, albite, aegirine, and accessory sphene and apatite. Lepidomelane is occasionally present. Secondary minerals are libnerite, cancrinite, and iron hydroxides.

Tinguaites are porphyritic in texture (Figures 3 and 4) with a trachytic to granitic ground-mass. Their porphyroblasts are represented largely by nepheline, also by K-feldspar and aegirine.

The quantitative ratios of minerals, computed on the integration table, are given in Table 2. Inclusions of gas bubbles and of extremely fine aegirine crystals are fairly common in nepheline. Some nepheline crystals are zoned (Figure 4), the zones being produced by alternating bands of different content of gas-fluid bubbles and aegirine needles.

Spectrographic analysis of nepheline has determined the presence (in %) of Sr and Ba, 0.3 to 0.6; Ga, 0.003; Bi and Pb, 0.03 to 0.06; Cu, 0.003; Ag, 0.0003; V, 0.0001; Mn, 0.0006 + 1; Ti, 0.06 to 0.09; and Fe, 0.3.

A. S. Marfunin's conoscopic measurement of



FIGURE 4. Tinguaite. Porphyritic segregations of nepheline (a), orthoclase (b) and aegirine (black) are surrounded by a fine-grained groundmass.

Thin section 1885: magnification 16X, crossed nicols.

feldspars on the Fedorov table (Figure 3), in thicker transparent sections, gave $2V = 65$ to $68 \pm (001)$, $\beta = 5.7^\circ$ (measured without cleavage in Carlsbad twins). According to the A. S. Marfunin chart (1960), this is orthoclase with a small deviation from the monoclinic system; it carries $Or_{90}Ab_{10}$.

In these rocks, both nepheline and especially K-feldspar have been markedly replaced by albite, of an unquestionably later origin. Relations between K-feldspar and nepheline are more complex: in some places K-feldspar is clearly xenomorphic to nepheline and replaces it; in other places, the situation is reversed. Probably, both were formed at about the same time but nepheline crystallization began somewhat before that of K-feldspar and ended after it.

In addition to these three, a principal component of tinguaite is aegirine which forms acicular crystals in porphyroblasts of nepheline and orthoclase, also long prismatic crystals in the porphyroblasts and groundmass. The optic angle of aegirine, measured on the Fedorov table, is 68 to 75° ; the extinction angle, $c\alpha = 2$ to 10° . In zoned aegirine crystals, the periphery is sometimes deeper colored than the central part. Aegirine is present in these rocks in two generations: in the first, it forms idiomorphic crystals in K-feldspar and nepheline; in the second, it fills up, together with albite, the interstices between these minerals. It follows that it began to crystallize somewhat earlier than K-feldspar and nepheline and completed the process after them.

A semi-quantitative spectrographic analysis of aegirine shows that the following elements

are usually present (in %): Ba and Sr, 0.6; Bo, 0.001; and Zr, 0.3; metals, Ga and Cu, 0.003; Zn, 0.03 to 0.06; and from the iron group, Ti, n; V and Mn, 0.3 to 0.6; and Ni, 0.003.

Typical accessory minerals in these rocks are sphene and apatite, with the sphene more common and more abundant. They are usually associated with aegirine. A spectrographic analysis of sphene is as follows (in %): Nb, 0.3; Y, 0.01; La, 0.03 to 0.06; Zr, 0.3; and Sr, 0.1; among metals, Cu, 0.003; and the iron group is represented, besides a large amount of Ti and Fe, by V and Mn - 0.01. It is of interest that additive elements, niobium and rare earths, typical of these tinguaites, are concentrated largely in the sphene, and have not been observed in aegirine and nepheline. On the other hand, in nepheline syenites (foyaites) occurring near the tinguaites, niobium and rare earths are present in both sphene and alkalic hornblende.

In addition to these minerals, synthetic concentrates of tinguaite contain isolated grains of zirconium and magnetite. Postmagmatic processes are comparatively inconspicuous in tinguaite, being expressed in a replacement of nepheline by cancrinite and liebnerite, less commonly by albite; and in albitization of K-feldspars. These processes were more intensive in fault zones, to the extent that the original rock has been almost completely replaced by albite and liebnerite. The albitization was accompanied by an addition of niobium and rare earths. The results of chemical analyses of tinguaites are given in Table 3.

Nepheline syenites (foyaite type) are fine-grained gray rocks consisting of K-feldspar,

Table 2

Quantitative Content of the Minerals in Alkalic Rocks (volume %)

Name of rock	Thin section No.	Minerals								other minerals
		nepheline	pseudo-morphs of leibnerite and scapolite after meioline	potassium feldspar	plagioclase	aegirine	aegirine-diopside	alkalic hornblende	sphene	
Tinguaité	1833	33.4	—	30.6	28.0	7.2	—	—	1.5	0.3
Same	1883 ¹	35.5	—	28.4	26.5	8.0	—	—	1.2	0.2
"	1884	34.6	—	28.6	27.4	8.3	—	—	1.0	—
"	1885	27.0	—	32.0	33.0	7.3	—	—	0.5	0.1
"	1886	36.5	—	25.4	28.2	8.7	—	—	0.8	0.2
	Average content	33.4	—	29.0	28.8	7.9	—	—	1.0	0.04
Nepheline syenite (of the foyaite type)	1902	—	7.4	50.3	25.6	1.8	0.5	14.0	3.4	0.12
Same	1902-b	—	6.7	46.6	26.3	2	0.5	14.7	2.8	0.8
"	(large section) 1900-a	—	3.4	53.4	29.1	isolated crystals	isolated crystals	14.0	1.7	0.2
"	1903	—	13.3	42.4	27.4	0.8	0.3	11.8	3.4	0.5
"	1906	—	10.5	40.3	32.5	1.3	isolated crystals	12.0	3.2	0.6
	Average content	—	8.2	46.6	28.2	1.3	0.3	12.1	2.8	0.06
										0.48



FIGURE 5. Nepheline syenite. Aegirine (e) is replaced by diopside (d).

Thin section 1902-b: Magnification 56X, without analyzer.

albite, nepheline (usually almost completely replaced by liebnerite and cancrinite), alkalic hornblende, and a small amount of diopside and aegirine; with accessory sphene and apatite; and secondary liebnerite, cancrinite, and iron hydroxides. Their texture is hypidiomorphic-granular, occasionally porphyritic, determined by the presence of alkalic hornblende porphyroblasts (Figure 6). Quantitative ratios of these minerals are given in Table 2.

Hornblende of nepheline syenite forms long prismatic crystals (0.5 to 4 mm) in nepheline

(Figure 6) and K-feldspar. It is noticeable in some segments that aegirine replaces crystals of diopside (Figure 5) and hornblende, and fills up interstices in the latter. The hornblende is usually zoned, with the central part deep drab-brown (pleochroic from deeper, along γ , to lighter along α) and the periphery blue-green (pleochroic from deep blue-green along γ to light green-yellow along α). Elongation, positive; $c\gamma$ from 18° to 36° ; $2V$ from -56° to -72° . Refractive indices for hornblende, measured by the immersion method for different zones are as follows: for the outer blue-green zone,

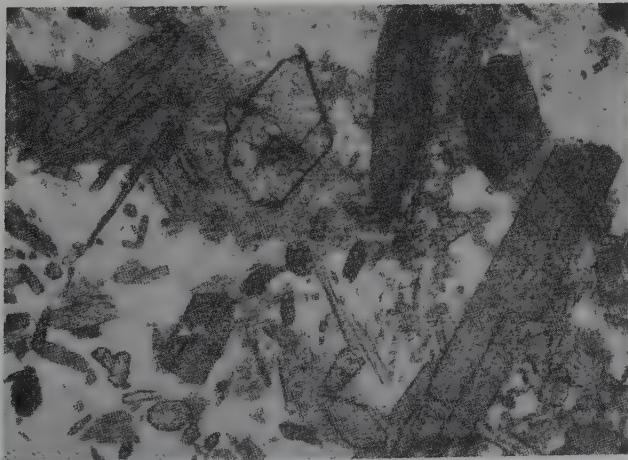


FIGURE 6. Nepheline syenite. Idiomorphic crystals of hornblende and sphene in nepheline (N) replaced by liebnerite.

Thin section 1902: magnification 35X, without analyzer.

Table 3

Results of Chemical Analyses of Alkalic Rocks of the Primor'ye (Soviet Far East) Alkalic Province (in %)

Oxides	Tinguaitite			Nepheline syenite, specimen sample 1886	Nepheline syenite, sample 1884	Nepheline syenite, sample 1892	Alkalic syenite, Northern Sakhalin	Alkalic syenite of Khibini f. Khibinsk massif, after B.M. Kupletsky (1937) spec. 2	Ave. comp. of khibinite of f. Khibinsk massif, after B.M. Kupletsky (1937)	Tinguaitite (average comp. after R. Daly)	Nepheline syenite (average comp. after R. Daly)	
	sample 1883	sample 1884	sample 1886									
SiO ₂	53.64	—	—	56.38	54.43	—	60.30	60.96	56.86	59.39	53.44	55.87
TiO ₂	0.42	—	—	1.58	2.03	—	0.71	0.55	0.53	0.80	0.87	1.50
Al ₂ O ₃	23.42	22.89	23.44	17.18	19.88	—	20.19	19.38	22.14	20.62	21.63	22.29
Fe ₂ O ₃	2.88	—	—	1.02	3.01	—	2.62	1.24	3.63	6.43	3.28	1.29
FeO	1.59	—	—	1.06	5.73	—	—	1.20	0.13	0.18	0.30	1.35
MnO	0.09	—	—	—	0.19	—	—	—	0.23	0.33	0.56	0.72
MgO	0.21	—	—	0.37	1.57	—	0.76	1.60	3.48	2.48	1.36	1.68
CaO	1.56	—	—	1.11	5.90	—	1.60	5.45	5.43	4.39	3.78	4.48
K ₂ O	5.33	5.48	5.10	4.80	4.46	3.50	5.10	6.06	6.08	7.42	7.08	6.01
Na ₂ O	10.47	10.90	11.44	8.10	8.09	7.07	7.07	7.07	7.07	7.07	9.85	9.68
H ₂ O-	0.20	—	—	0.07	0.21	—	—	—	—	0.07	—	—
H ₂ O ⁺	0.58	—	—	—	0.37	—	1.49	—	—	3.29	1.00	—
Not anal.	—	—	—	Not analyzed	—	—	0.21	Not anal.	0.07	0.40	None	—
P ₂ O ₅	0.016	—	—	Not anal.	0.009	—	—	Not anal.	—	0.07	0.07	0.06
Li ₂ O	0.15	—	—	Not anal.	0.07	—	—	Not anal.	—	None	Not anal.	0.25
F	None	—	—	None	—	—	—	None	—	—	—	Not anal.
P ₂ O ₅	Not anal.	—	—	Not anal.	—	—	—	Not anal.	—	—	—	—
Others	—	—	—	1.25	—	—	—	—	—	1.05	1.38	—
Total	100.54	—	—	100.64	100.21	—	100.44	100.06	99.95	100.34	100.00	—
												100.77
												100.35

Figures taken from A.N. Zavaritsky

<i>t</i>	0.6	—	2.4	2.7	0.9	0.7	0.7	1.0	1.2	0.7	0.7	0.5	1.2
<i>φ</i>	41.0	—	10.8	16.7	18.5	56.7	46.0	41.8	39.4	26.7	35.5	29.8	29.8
<i>n</i>	75.0	—	72.5	63.0	62.3	71.7	73.0	47.8	41.5	59.0	70.9	69.7	69.7
<i>α</i>	—	—	—	—	—	—	—	—	—	—	—	—	—
<i>Q</i>	—37.9	—	—	—	—	—	—	—	—	—	—	—	—
<i>c</i>	27.2	—	—	—	—	—	—	—	—	—	—	—	—
<i>a</i>	10.4	—	—	—	—	—	—	—	—	—	—	—	—
<i>c</i>	5.7	—	—	—	—	—	—	—	—	—	—	—	—

Samples 1883, 1884, 1886, 1902 and 1892 were analyzed from the author's materials in the I.G.E.M. chemical laboratory of the Academy of Sciences of the U.S.S.R. by the analysts V.I. Klytina, L.M. Krutitskaya and G.Ye. Kalenchuk; specimen 1 was analyzed in V.S.E.G.E.I. by M.I. Freyde and was taken from N.A. Belyayevskiy; the chemical analyses of the nepheline syenites and alkalic syenites of northern Sakhalin were taken from the paper by V.M. Fon-Derviz (1915), and the chemical analyses of the alkalic syenites of southern Sakhalin (the Morotu district) from the paper by K. Jagi (1953). The average compositions were taken from the paper by B.M. Kupletskiy (1937).

$\gamma = 1.677 \pm 0.002$; $\alpha = 1.660 \pm 0.002$; for the interior drab-brown zone, $\gamma = 1.684 \pm 0.002$, $\alpha = 1.668 \pm 0.002$. Judging from these data, this is hornblende of an intermediate magnesium-rich hastingsite-barkevikite-hastingsite series.

According to spectrographic analysis, constant components of this hornblende are (in %) Nb, 0.003 to 0.006; Zr, 0.03; Be, 0.0001; Ba and Sr, 0.03. Present among the metals are Zn, 0.03; Sn, Pb, and Cu, 0.003; the iron group is represented, besides the iron itself, by Ti, n; V, 0.06; Co and Ni, 0.003 to 0.006.

Accessory minerals in nepheline syenites, as in the tinguaites, are sphene, more abundant here, and apatite (see Table 2); the sphene usually carries small acicular crystals of hornblende, missing in sphene.

Spectrographic analysis of sphene in nepheline syenites is as follows (in %): Nb, 0.03 to 0.06; Zr, Y, and La, 0.01 to 0.03; Sr, 0.1; P, 0.03; Sn, 0.03; Cu and Ga, 0.006. In addition to much Fe and Ti, the iron group is represented by Mn and V (0.01 to 0.03%). Especially interesting is the presence in sphene of Nb and rare earths, typical alkalic rock elements, as well as the associated post-magmatic formations, in an amount larger than in alkalic hornblendes. Also of importance is the presence of tin, an element typical not of alkalic rocks but rather of non-contemporaneous granitoids in the Maritime Province and of the accompanying post-magmatic formations.

Post-magmatic processes in these rocks were rather intensive, being reflected in the replacement of nepheline by liebenite and less commonly by cancrinite; in albitization of K-feldspar and nepheline; and in replacement of the alkalic hornblende (magnesium-rich hastingsite-barkevikite-hastingsite series) by aegirine. In other words, postmagmatic solutions accompanying these alkalic rocks are marked by a higher sodium content. The results of chemical analysis of the nepheline syenites are presented in Table 3.

An analysis of figures in Table 3 and of the chemical composition diagram constructed by the A.N. Zavaritskiy method (Figure 7) shows that tinguaites (sample 1883) approach the average composition of khibinites from the Khibinsk massif (from B.M. Kupletskiy's data) and of R. Daly's foyaite. Nepheline syenites of this area (specimen 10, sample 1902) and those from North Sakhalin (Table 3; Figure 3) are similar to the average composition of miaskite and foyaite, although sample 1902 differs sharply in its lower alkalic content and a higher content of calcium and

Table 4

Distribution of Elements as Admixtures in the Rock-Forming and Accessory Minerals of the Ultra-basic and Alkalic Rocks of the Region Investigated, as well as their Accompanying Post-magmatic Formations,¹ in %

Elements	Pyroxenite				Tinguaita			
	in the rock	in the rock-forming minerals		in the accessory minerals		in the rock	in the rock-forming minerals	
		augite	apatite	titano-magnetite	nepheline		aegirine	sphene
Be	—	—	—	—	0.0001	—	0.0001	—
Li	—	—	—	—	—	—	—	—
Ba	—	—	—	—	0.01— 0.06	0.3— 0.6	0.01— 0.03	—
Sr	0.01— 0.03	0.01— 0.03	0.1	0.01— 0.03	0.01— 0.06	0.3— 0.6	0.1	0.1
Cs	—	—	Not analyzed	—	—	—	—	—
Rb	—	—	—	—	—	—	—	—
Zr	0.001— 0.003	0.03	0.001	0.01	0.01— 0.06	—	0.1—0.3	0.1—0.3
Y	—	—	0.01— 0.03	—	0—0.06	—	—	0.001
La	—	—	0.01	—	0—0.06	—	—	0.01— 0.03
Ce	—	—	0.1	—	0.001—	—	—	—
Nb	—	—	—	—	0.06	—	—	0.3—0.6
Ta	—	—	—	—	—	—	—	—
CaF	—	Not anal.	n+	—	Not analyzed	—	—	—
P	n	—	n+	—	—	—	—	—
Cl	—	—	Not analyzed	—	—	—	—	—
Sc	—	—	—	—	—	—	—	—
Cu	0.003— 0.006	0.001— 0.003	0.001—	0.001— 0.003	0.0001— 0.001	0.001— 0.003	0.0003	0.001
Pb	—	—	—	—	—	0.03— 0.06	—	—
Zn	0.04— 0.03	0.01— 0.03	—	0.01— 0.03	—	—	0.01— 0.03	—
Ga	0.001— 0.003	—	0.001— 0.003	0.001— 0.003	0.001— 0.003	0.003— 0.006	0.003	—
Ge	—	—	—	—	—	—	—	—
Sn	—	—	—	—	—	—	0.001— 0.003	—
Tl	—	—	—	—	—	—	—	—
As	—	—	—	—	—	—	—	—
Sb	—	—	—	—	—	—	—	—
Bi	—	—	—	—	—	0.03— 0.06	—	—
Ag	—	—	—	—	—	0.0001	—	—
Mo	—	—	—	—	—	—	—	—
W	—	—	—	—	—	—	—	—
Fe	n+	n+	3	n+	3—6	0.6—0.9 0.03—	n+— 0.6—0.9	1—3 n+
Ti	n	1—3	0.3—0.6	3—6	0.3—0.6	0.06	—	—
Mn	0.1	0.1—0.3	0.01	0.3—0.6 0.01—	0.01— 0.06	0.0006	0.1—0.3 0.03	0.01— 0.03
V	0.01— 0.03	0.01— 0.03	0.006	0.03	0.001— 0.01	0.0001	0.03— 0.06	0.01
Cr	0.003— 0.006	0.01— 0.03	—	0.003	0—0.001	—	—	—
Ni	0.001— 0.003	0.001— 0.003	—	0.001— 0.003	0—0.001	—	0.001— 0.003	—
Co	0.003— 0.006	0.001— 0.003	—	0.001	0—0.001	—	0.001— 0.003	—

¹ This table was prepared from semi-quantitative spectrographic analyses made in the I.G.E.M. spectrum laboratory of the Academy of Sciences of the U.S.S.R. by the analysts A.S. Dudykina and A.S. Martynova. The apatite in the tinguaita and nepheline syenite, as well as the nepheline in the latter, have not yet been analyzed.

Table 4 (continued)

Nepheline syenite (of the foyaite type)				Albitized nepheline syenite in the rock	Albitite			Carbonate rocks		
in the rock	in the rock forming minerals	in the accessory minerals	in the rock		in the minerals		in the rock	content in minerals		
	hastingsite	sphene			albite	apatite		carbonates	carbonates	apatite
0.0001	0.0001	—	0.0001— 0.03	0.0001— 0.03	—	—	—	—	—	—
—	—	—	0—0.03	—	—	—	—	—	—	—
0.03— 0.3	0.03— 0.06	—	0.01— 0.06	0.01— 0.06	0.03— 0.6	0.1— 0.3	0.03— 0.6	0.03— 0.03	0.01— 0.03	0.003— 0.006
0.03— 0.6	0.03— 0.06	0.1	0.03— 0.6	0.1—0.3— 0.1—0.3	0.1—0.3— 0.1	0.1—0.3— 0.1	0.01— 0.3	0.3— 0.6	0.3— 0.6	0.3— 0.6
Not Analyzed										
0.001— 0.06	0.03	0.1—0.3	0.03— 0.9	0.01— 0.03	0.003— 0.006	0.003	0—0.06	0.01— 0.03	0.003— 0.006	
0.06	—	0.01— 0.03	0—0.3	0.03— 0.6	—	0.003	0—0.06	0.01— 0.03	0.01— 0.03	
0.06	—	0.01— 0.03	0—0.06	—	—	0.001	0—0.06	0.1— 0.3	0.03— 0.06	
0.06	—	0.03	—	—	—	—	—	0.3	0.06	
—	—	—	0—0.3	—	—	—	—	—	0.3— 0.6	
0.001— 0.09	0.001— 0.003	0.03— 0.06	0.01— 0.6	0.003— 0.006	0.001— 0.005	—	0—0.001	—	—	
—	—	—	—	—	—	—	—	—	—	
0—0.3	—	Not analyzed	—	—	—	—	Not anal.	n	n	
—	—	0.1—0.3	—	—	—	n+	0.3—3	n+	n+	
Not Analyzed										
0.0001— 0.003	0.001— 0.003	0.003	0.0001— 0.001	0.001— 0.003	0.0001— 0.0003	—	0.001— 0.006	0.003— 0.006	0.001— 0.006	
—	0.003— 0.006	—	0.001— 0.06	—	—	—	0—0.006	0.003— 0.006	—	
—	0.01— 0.03	—	0—0.3	0.01— 0.03	—	—	—	0.06— 0.09	—	
0.001— 0.003	0.003	0.001— 0.003	0.003— 0.06	0.006— 0.009	0.003	0.0001	0.001— 0.006	—	—	
—	—	—	—	—	—	—	—	—	—	
—	0.003— 0.006	0.01— 0.03	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	
6—9	n+	3—6	0.3—3	1—3	0.6—0.9	0.3— 0.6	0.3—3	1—3	0.3— 0.6	
1—3	1—3	n+	0.03—3	0.3—0.9	0.01— 0.03	—	0.001— 0.4	0.1— 0.3	—	
0.3—0.6	0.1—0.3	0.01— 0.03	0.03— 0.6	0.1—0.3	0.001	0.0001	0.001— 0.1	0.03— 0.06	0.01— 0.03	
0.001— 0.01	0.01— 0.03	0.1— 0.03	0.0001— 0.006	0.006— 0.009	0.0001	0.0001	0—0.06	0.003— 0.006	0.001— 0.003	
0— 0.001	—	—	0—0.006	0.001— 0.006	—	—	0—0.003	—	—	
0— 0.001	—	—	—	—	—	—	—	—	—	
0— 0.001	0.001— 0.003	—	0—0.003	—	—	—	0—0.003	—	—	

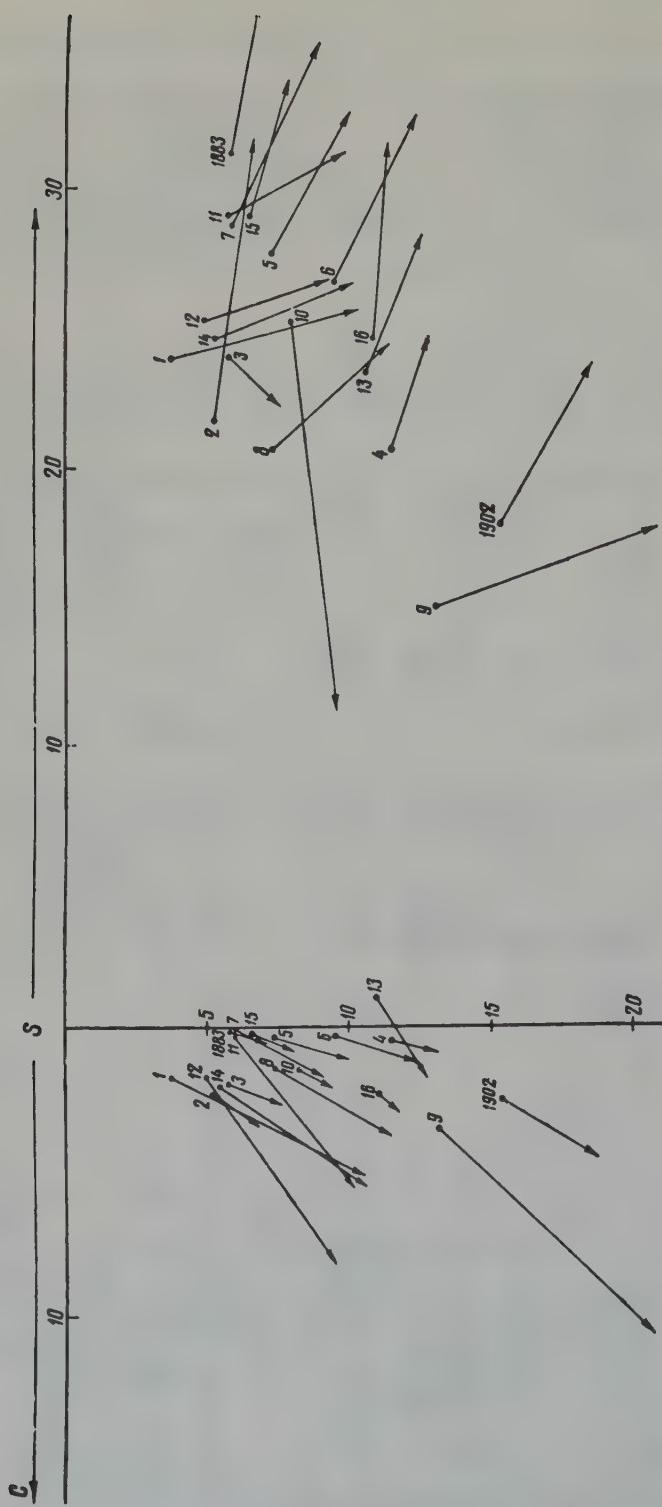


FIGURE 7. Diagram of the chemical composition of the alkalic rocks of Sikhote-Alin' and Sakhalin

1883, tinguaite of Sikhote-Alin; 1902, [10], nepheline syenites of northern Sakhalin; 1 - nepheline syenites of Sikhote-Alin; 1 - nepheline syenites of northern Sakhalin; 2, 3, 4 - alkalic syenites of Sakhalin; 5 - average composition of tinguaite, after Daly; 6 - average composition of nepheline syenite, after Daly; 7 - average composition of alkalic syenite, after Daly; 8 - average composition of foyaite, after Daly; 9 - average composition of alkali-earth syenite, after Daly; 11 - average composition of khibinsk massif, after B.M. Kupletskiy; 12 - average composition of foyaite of the Khibinsk massif, after B.M. Kupletskiy; 13 - average composition of masicite, after B.M. Kupletskiy; 15 - nepheline syenite, resembling khibinite, from southeastern Tuva, after R.M. Yashina; 16 - nepheline syenite, miaskitic, from southeastern Tuva, after R.M. Yashina.

iron,³ while specimen 10 is supersaturated with alumina, which is not at all typical of alkalic rocks. Interestingly, nepheline syenites of Sikhote-Alin are high in TiO_2 (1.58 to 2.03%) which is also typical of the Khibinsk massif foyaite.

The Sikhote-Alin tinguaite (samples 1883, 1884, 1886) carry considerably more alkaline and calcium, magnesium, and iron oxides, and less titanium oxide, than in the foyaite-type nepheline syenites (samples 1902, 1892, specimen 10). The average content of alkalies (in %) in tinguaite is: Na_2O , 10.94; K_2O , 5.3; in nepheline syenites: Na_2O , 7.10; K_2O , 4.28; average content of TiO_2 in tinguaite, 0.42, and in nepheline syenites, 1.80. The lower Na_2O content in nepheline syenite is explained by a considerably lower nepheline and aegirine content, comparable with tinguaite, while the larger amount of oxides of calcium, magnesium, and iron is due to the presence of a large amount of dark minerals represented by hastingsite and barkevikite; the higher TiO_2 content is related to the presence of much sphene. The apatite factor of tinguaite is one, and for nepheline syenite, 0.75.

Thus, there are two types of nepheline rocks in this area: those approaching the agpaitic type (samples 1883, 1884, and 1886) and those approaching miaskite (samples, 1902, 1892, specimen 10). It is important to note that the first type is characterized by a higher Fe_2O_3 content, compared with FeO, and by a higher content of fluorine, water, lithium, and zirconium, and by a considerably lower TiO_2 content. Nepheline syenites of Sikhote-Alin and Sakhalin are marked by their lower alkalic content, the absence of the Fe_2O_3 predominance over FeO, by a considerably higher content of CaO and TiO_2 , and by a lower content of F, H_2O , P, and Zr.

These two types of nepheline rocks differ also in mineral composition; agpaitic rocks contain more nepheline and aegirine, less sphene and apatite; the miaskite rocks are richer in hastingsite, barkevikite, and sphene.

This description of ours is in complete agreement with V. I. Gerasimovskiy's data [5] on mineral and geochemical features of agpaitic and miaskitic alkalic rocks.

The presence in the central Sikhote-Alin structure suture, of alkalic rocks represented by veins of tinguaite similar to agpaitic-type rocks, suggests the presence in larger intrusive

³This is due to the fact that in the rocks described, the nepheline is almost completely replaced by liebnerite and other minerals. Moreover these nepheline syenites contain large amounts of alkalic hornblende, represented by hastingsite.

bodies, of zirconosilicates, titanosilicates of sodium and calcium, and of minerals from the perovskite-pyrochlore group.

An analysis of the chemical composition for the Sakhalin alkalic rocks (Table 3), and its comparison with the average rock types of R. Daly, suggests that they approach the average composition of alkalic syenites (Figure 7), differing from it somewhat in their higher content of Na_2O and Al_2O_3 , and in a lower MgO content. The Sakhalin alkalic syenites are inconsistent in composition, as reflected in their different content of K_2O , Al_2O_3 , Fe_2O_3 , FeO, and CaO. In their chemical composition, the Sakhalin alkalic syenites are similar to nepheline syenites of this region, except for a somewhat lower alkalic content.

The following preliminary conclusions can be made from the distribution of additive elements in alkalic and ultrabasic rocks of this region and in their rock-forming and accessory minerals: accessory elements of the ultrabasic rocks are Sr, Zr, P, Cu, Zn, Ga, Ti, Mn, V, La, Nb, Cu, Ga, Ti, and Mn. In addition, alkalic rocks may carry very small amounts of Be, Ce, Pb, Zn, Sn, Bi, Ag, Cr, Ni, and Co.

A comparison of the trace-element content of alkalic and ultrabasic rocks shows that it is different to a certain extent: Ba, Y, La, and Nb are present only in alkalic rocks; at the same time these rocks carry elements common to both: Sr, Zr, Cu, Ga, and Ti. Of interest is the persistence of Y and La in albites of the ultrabasic rocks as well as in albitites and carbonatites. These data point to a common magmatic source for the ultrabasic and alkalic rocks.

In analyzing the behavior of trace elements in accessory and rock-forming minerals of tinguaite and nepheline syenites, we note that Zr, Nb, and Zn are concentrated in dark (aegirine, hastingsite) and accessory minerals (sphene), with the amount of Nb increasing in the latter; Be is concentrated only in aegirine and hastingsite; and Y, La, and Ce, only in sphene and apatite.

POST-MAGMATIC PROCESSES AFFECTING ALKALIC ROCKS

Alkalic rocks here described have undergone liebneritization and even more intensive albitization. This region exhibits all stages of a gradual albitization, leading to the formation of peculiar rocks consisting mostly of albite (Figure 8). Albitized varieties of nepheline syenites as well as albitites are marked by a content of Be, Zr, Y, La, Ce, and Nb, higher than in unaltered varieties (Table 4). It may be assumed, then, that the precipitation of these elements, present in both rock-forming and



FIGURE 8. Albitized nepheline syenite.

Thin section 1848: magnification 56X, crossed nicols.

accessory minerals of nepheline syenite and tinguaita, took place at initial stages at their magmatic source, during the crystallization of alkalic rocks; an accumulation of alkalic rocks took place later on, in connection with post-magmatic processes.

Locally associated with pyroxenite and nepheline syenite are peculiar carbonate rocks (Figure 9) consisting largely of carbonates (up to 80%), apatite (up to 15%) and plagioclase (up

to 25%). The mode of their occurrence has not been determined, as yet; although their typical accessory elements, as in nepheline syenites, are Sr, Zr, Y, La, Ce, and Ti (Table 4), with a higher content of yttrium and other rare-earth elements. Like pyroxenites, the carbonate rocks are rich in phosphorus and quite poor in Cr and Co, the typical elements of ultrabasic rocks. Trace elements in apatite of these carbonate rocks are quite similar in composition to those in the pyroxenite apatite.



FIGURE 9. Carbonate rocks with a large amount of apatite (an).

Thin section 1900: magnification 63X, without analyzer.

SUMMARY

1. These new data considerably extend G. A. Gapeyeva's alkalic province (1953) which may turn out to be of a practical as well as scientific importance.
2. Identifiable among intrusive rocks of the Maritime Province are nepheline syenite, tinguaita, and other varieties, occurring in dikes and small stock-like bodies. These rocks are spatially and perhaps genetically related to ultrabasics, as witness the presence in both alkalic and ultrabasic rocks, along with accessory elements typical of both, of common accessory elements present in pyroxenite, as well as in nepheline syenite.
3. Alkalic rocks are associated with major tectonic deformations, major faults and the associated plume fractures, late Mesozoic in age, probably Late Cretaceous.
4. Post-magmatic processes, accompanying the alkalic rocks, are reflected in liebneritization and albitization. The albitization was especially intensive; it determined the formation of monomineral albitic rocks.
5. Conspicuous in alkalic rocks and the accompanying post-magmatic formations is a group of enduring elements whose concentration began at early stages of development at their magmatic source, during the crystallization of rock-forming and accessory minerals of nepheline syenite, and whose accumulation took place later on, in connection with the activity of post-magmatic solutions.
6. The association of alkalic rocks with major faults and their close spatial relationship with ultrabasic rocks make it possible to designate areas favorable for prospecting for mineralization accompanying them. Of interest in this respect are the central Sikhote-Alin and the western faults. Priority should be given to the study of ultrabasic rocks developed within the central Sikhote-Alin fault.

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Received, 12 May 1960

GEOCHEMICAL CRITERIA FOR THE RELATIONSHIP OF ENDOGENETIC MAGNETITE MINERALIZATION IN THE SIBERIAN PLATFORM AND THE TRAPROCK MAGMA DIFFERENTIATES¹

by

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The origin of magnetite deposits in the Siberian platform, especially of the long mined and well known Angara-Ilim deposits, has been a subject of many publications which demonstrate convincingly their genetic relationship to a basic traprock magma [1, 4, 5, 9, 11, 14].

However, as shown by recent studies, these traprocks are quite diversified, both geochemically and mineralogically, raising some practical and urgent questions. Which traprock magma could have been the source of the mineralizing solutions? What is the distribution of these traprocks in structures?

Our detailed study of traprock in the southeastern part of the Siberian platform, where there are many magnetite deposits and ore showings, has provided a concrete approach to this problem, as well as basic criteria in the search for iron-ore deposits. First it was imperative to determine the spatial and paragenetic relation between ore deposits and the traprock formation, as well as their mineral and geochemical features and their structural position.

We shall consider, one by one, the main criteria for this relationship between magnetite mineralization and traprock.

A. GEOLOGIC CRITERIA FOR THE RELATIONSHIP BETWEEN MINERALIZATION AND IGNEOUS ACTIVITY

As we have already noted [3, 4], magnetite deposits in the southeastern part of the Siberian platform are concentrated in certain zones of similar geologic and tectonic conditions. Two such zones can be designated from the data extant: a zone of "local folds", traceable along the western margin of the Angara-Lena Lower Paleozoic downwarp, at its junction with the

eastern side of the Tunguska syncline;² and a zone extending along the northwestern limb of the Aldan anticlise, at its junction with the east margin of the Berezovsk trough. Both zones have a consistent northeasterly trend and are characterized by common geologic and tectonic conditions.

Thus, one of the structural features of the first (western) zone of "local folds" is, according to N. S. Zaytsev [6], the presence of linear anticlinal folds, not accompanied by corresponding synclines and standing out sharply on the background of flat, locally almost horizontal, lower Paleozoic rocks. Quite common here are Lower Cambrian saline carbonates exposed in anticlinal cores. The anticlines are characterized by the development of a single limb, with the other limb commonly cut off, dropped down, or reduced in thickness and accompanied by a series of shears, thrust, and normal faults.

The "zone of local folds", like other structures in the Siberian platform, is characterized by earlier Caledonian disturbances and by later Hercinian ones and by phases of traprock volcanism probably associated with the Hercinian disturbance. The traprock volcanism is differentiated into two stages: 1) early Hercinian, occurring at the Carboniferous-Permian boundary and partially, perhaps, with the Upper and Lower Permian boundary; and 2) late Hercinian, associated with the Permo-Triassic.³ These deformations have brought about two fault trends in this area: north-northwest (older) and north-east (younger). Volcanic centers (P. Ye. Offman's explosion vents) were formed in post-Hercinian time, along a southern extension of the "local folds' zone", in the Angara-Ilim

¹Petrokhimicheskiye kriterii svyazi endogennoogo magnetitovogo orudeniya na Sibirskeoy plafomme s differentsiatami trappovoy magmy.

²The localization of iron-ore deposits in this zone was pointed out earlier by V.S. Sobolev (1931), V. P. Maslov (1932), and G.F. Krashennikov, and later by M.A. Ivashchenko (1956), and T.N. Spizhar-skii (1958).

³We shall not dwell here on the later, Jurassic dislocations, since these do not have any bearing on the problem considered here.

region and farther on to the north, in the Nepa River basin. These explosion vents are missing in the eastern (second) zone; there are instead dome-like structures and numerous faults trending north-northwest to northeast and patched with younger traprock dikes. In these trends, there is a community of geologic and tectonic conditions of the two zones. Concentrated in the area of the first (western) zone are the Angara-Ilim and Nepa groups of deposits; Biryuk, Daban, and Dirin-Yuryakh are located (from the southwest to northeast) in the second (eastern) zone.

Outside these zones, a showing of magnetite mineralization has been observed in the Baykal-Patom highland spur (area of Borus River).

However, as we shall see, it is associated with an earlier stage of traprock volcanism (Figure 1).

Within the area under study, magnetite mineralization is associated with differentiated traprock of three types:

1) poorly differentiated quartz-olivine microdiabase, presumably early Hercinian (C-P); this mineralization is restricted to the contact of a dike-like body with Lower Cambrian limestones (Borus River area);

2) acid differentiates of a late Hercinian (T) traprock magma — leucodolerites (Dirin-Yuryakh deposit);

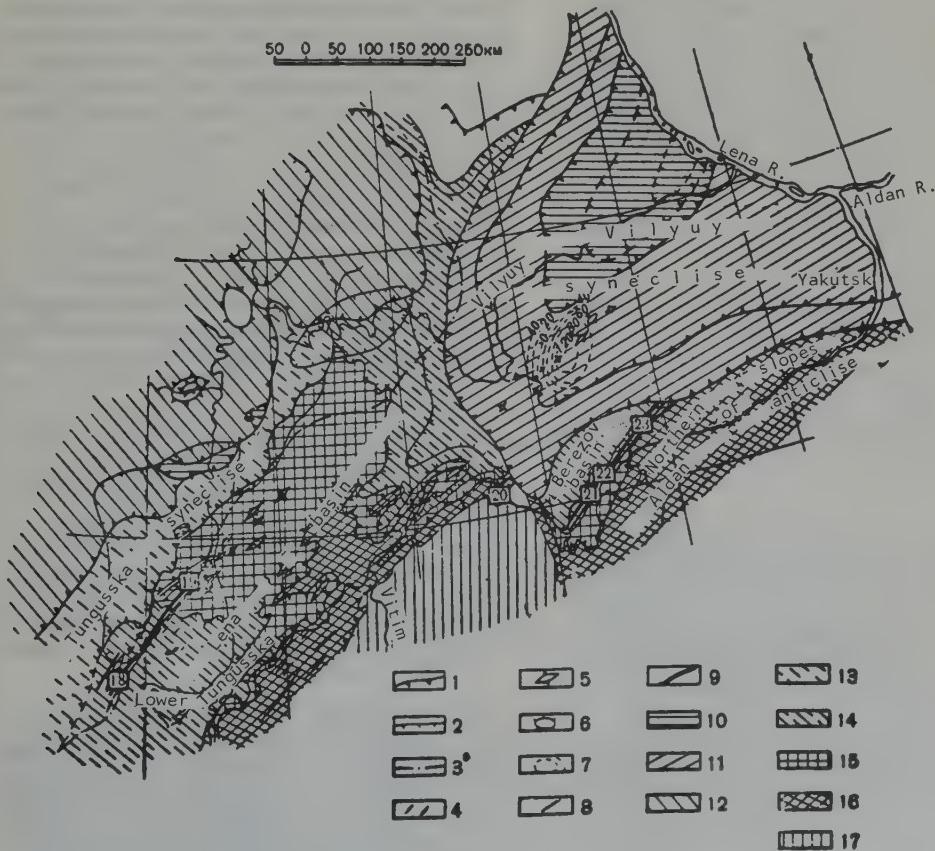


FIGURE 1. Sketch map showing the distribution of the zones of magnetite mineralization in the southeastern part of the Siberian platform (geologic-tectonic base after N.S. Zaytsev, 1951), in 1959.

1 - boundaries of structural stages; 2 - tentative structural lines; 3 - boundaries of areas of widespread occurrence of traprock; 4 - linear elongated anticlines; 5 - brachyanticlines and domial uplifts; 6 - indistinct anticlinal uplifts; 7 - gravity anomalies; 8 - major faults; 9 - zones of magnetite mineralization; 10 - Late Cretaceous; 11 - Jurassic and Lower Cretaceous; 12 - Upper Permian and Triassic; 13 - Carboiferous and Permian; 14 - Ordovician and Silurian; 15 - Upper Cambrian; 16 - Lower and Middle Cambrian; 17 - Proterozoic; 18 - Korshunikh deposit; 19 - Nepskaya group of deposits; 20 - ore occurrence in the area of Borus; 21 - Biryuk deposit; 22 - Daban deposit; 23 - Dirin-Yuryakh deposit.

3) late Hercinian sub-alkalic dolerites (Korshunikhino deposit) in the Angara-Ilim region; presumably one of the Nepa group of deposits).

These traprock magma differentiates form largely dike-like, butting bodies, 50 to 75 m thick, seldom thicker. They occur either in ore fields (Korshunikhino, the Angara-Ilim region) or in the immediate vicinity of ore bodies in which case they form an endocontact zone of strongly altered enclosing rocks (carbonates; Dirin-Yuryakh deposit, the Yakutian A. S. S. R.; ore showings in the Borus area).⁴

Because of the spatial relationship of mineralization to these types of differentiated traprocks, the similarity in mineralization of the lateral rocks in contact with them and in the mineralization zones, and the geochemical affinity of the vein and accessory magnetites of these traprocks, the traprock may be regarded as apophyses of deep-seated magmatic bodies. As such, they can be used in determining the nature of their deeper sources and their genetic relationship with the ore bodies.

Ore deposits associated with traprock of the first and second type and occurring in the Lower Cambrian limestone-dolomite section are of no particular commercial value. They are concentrated as thin veins along the contacts with intrusive bodies (Dirin-Yuryakh deposit, Borus River area) or outside the traprock, along the fault zones of crushing, where they occur mostly in stocks (Daban deposit) and less commonly in veins, 0.3 to 0.5 m thick (Biryuk deposit).

Most interesting is the third type of traprock, with which are associated the Korshunikhino and possibly the other Angara-Ilim deposits, confined largely to volcanic veins. The distribution of the veins along major faults and associated secondary faults indicates the considerable role of tectonics in forming commercial ore deposits. These weakened segments were most favorable for explosive activity and the formation of volcanic vents which became channels for traprock magma and the associated emanations. The commercial value of a deposit is closely related to geochemical and mineralogic properties of traprock with which it is paragenetically associated.

B. GEOCHEMICAL AND MINERALOGIC CRITERIA OF RELATIONSHIP BETWEEN IGNEOUS ACTIVITY AND MINERALIZATION

Neither the quartz-olivine microdiabase (type one) nor leucodolerite (type two) could

have been instrumental in forming large commercial ore deposits. The first are poorly differentiated, low in volatiles, and with only a very small amount of the ore (ferruginous) component. The second is characterized by a higher SiO_2 and Al_2O_3 content and a lower content of CaO and MgO ; it has a higher ferruginous factor $\left(\frac{\text{FeO} + \text{Fe}_2\text{O}_3}{\text{FeO} + \text{Fe}_2\text{O}_3 + \text{MgO}} \times 100 \right)$ and a lower ratio. Moreover, these traprocks are poor in a number of volatile components (F, P, etc.) very active in the mineralization process.

Quite different in their mineralogic and geochemical properties are sub-alkalic traprocks (type three) which do have commercial iron-ore deposits associated with them. They have a higher basicity, lime content, and alkalinity, with the resulting formation of an intermediate plagioclase-andesine instead of labradorite and labradorite-bytownite, of alkalic pyroxenite - aegirine-augite with 40% or more of the aegirine component ($\text{NaFeSi}_2\text{O}_6$), also with an extensive development of diopside, apatite, and sphene. Especially significant is the lowering of the ferruginous factor $\left(\frac{\text{FeO} + \text{Fe}_2\text{O}_3}{\text{FeO} + \text{Fe}_2\text{O}_3 + \text{MgO}} \times 100 \right)$ in these traprocks (40 as against 60), even compared with more acid traprock differentiates, the leucodolerites; conversely, they have a higher $\text{Fe}_2\text{O}_3/\text{FeO}$ ratio. Sub-alkalic dolerites are characterized by their deviation toward agpaitic⁵ systems with $\frac{\text{Na}_2\text{O} + \text{K}_2\text{O}}{\text{Al}_2\text{O}_3}$ up to 8.

Another peculiarity of sub-alkalic traprocks is their higher content of apatite, pyrite, sphene, and titanomagnetite, with the presence of tiotite, hornblende, fluorite, galena, and topaz - evidence of a volatile-rich source magma. According to A. G. Betekhtin [5] and others, the higher pyrite content in sub-alkalic dolerites of the Korshunikhino unit, suggests a very low hydrogen-ion concentration in the melt, as well as an alkaline medium favorable for sulfide precipitation.

Leading elements in sub-alkalic traprock are P, F, S, and Cl, all components of a basic traprock magma; present along with them are elements typical of more acid alkalic magmas: Na, K, Li, Rb, Cu, Zn, and Pb,⁶ and often Be and Mo. Spectrographic analyses of sub-alkalic traprocks and their altered lateral host rocks, as well as of the associated magnetites and

⁵According to A. Ye. Fersman [15], for the apatite type

$$\frac{\text{Na}_2\text{O} + \text{K}_2\text{O}}{\text{Al}_2\text{O}_3} = 1 - 1.5.$$

⁶It is not impossible that some of the Li and Pb was taken by the magma from the enclosing rocks (limestone, sandstone and other types).

⁴This is given in greater detail in our paper [4].

vein ores, have shown their geochemical affinity (Tables 1 and 2). This is also suggested by the similarity of accessory minerals in traprock and in new formations in near-by altered rocks: common to both are diopside, fluorite, chlorite, apatite, and pyrite, i.e., a mineral assemblage typical on the whole of sub-alkalic traprocks.

The presence in altered ore-contact rocks, of molybdenite, muscovite, biotite, hornblende, and occasional fluorite, emphasizes the importance of volatiles in the formation of iron-ore deposits.

The genetic affinity between sub-alkalic traprocks and vein ores is emphasized by the similarity in chemical composition of titanomagnetite sub-alkalic traprocks and vein ores. Present in both are Ti, V, Mn, Co, Ni, Cu, Zn, Ga, and Mo. Most significant is the presence of Zn and Mo in titanomagnetic sub-alkalic traprocks and not in the other varieties.

C. ORIGIN OF SUB-ALKALIC TRAPROCK

Earlier works by the students of Siberian traprocks, specifically N. P. Anikeyev [1], V. S. Sobolev [14], and others, noted the peculiar features of the so-called "Angara-type" traprocks, developed in the Angara-Ilim region. Plagioclase in these traprocks is represented by andesine with 43 to 49% anorthite, while traprocks with labradorite and labradorite-bytownite are developed outside the ore deposits. Even at that time, all authors emphasized the difference between the Angara-Ilim gabbro-diabase and traprock from other regions.

It was pointed out that the Korshunikhino traprocks differ from common intrusive sills and are perhaps special "deep-seated traprocks".

Unfortunately, no detailed geochemical and mineralogic study has been done on the Angara-Ilim deposits, so that it is impossible to decide on their relationship to a special "angara-type" traprock. Accordingly, all authors have confined themselves to general considerations on the relationship of magnetite deposits to a basic traprock magma [5, 11, 12] or its differentiates [1, 9].

In noting the importance of volatile components in the formation of ore deposits, all authors emphasized the importance of volatiles associated with basic magmas alone, such as water, carbon dioxide, phosphorus, chlorine, and to a smaller extent fluorine; at the same time, they pointed to the total absence of K, Na, Li, and Rb, associated with more acid magmas.

Our own data lead, as we have seen, to somewhat different conclusions, viz: the traprock magma is much richer in volatiles which are unevenly distributed in different kinds of traprock magma; and their concentration is the highest in sub-alkalic differentiates, probably hybridized.

These great differences between sub-alkalic rocks and other traprock formations suggest a deeper cause of this phenomenon, at the point of origin. Tectonic conditions in the area of these traprocks, at a junction of variously trending structures, with wide fault and crushed zones, were favorable for recurrent traprock volcanism, beginning in the Permian or Carboniferous through the Early Jurassic. The high permeability of these rocks, along with the presence of numerous faults often involving the crystalline basement, as well as the development of domal structures, favored a penetration of the sedimentary mantle by the magma, often forming "intermediate hearths" which fed subsequently (in new tectonic movements) the smaller piercement intrusions (dikes and stocks). The preponderance of Lower Cambrian saline-rich carbonate and calcareous rocks suggests that these intermediate magmatic centers could have been associated with them; this view is supported by the considerable thickness of these deposits, commonly measured in kilometers.

Such intermediate magmatic centers in carbonate deposits could not have remained passive; they were undoubtedly accompanied by a reaction of the adjacent substances and by a possible collapse and assimilation of the enclosing rocks.

Such an assimilation of deep carbonate or calcareous rocks would be accompanied by an addition to the magma of Ca, Mg, and possibly alkalies (Na); also the volatiles with CO₂ and H₂O probably the most prominent. A complete assimilation of the enclosing carbonate rocks, without any relicts, is suggested by the perfect crystalline structure of sub-alkalic dolerites, a feature of plutonic rocks; by the more or less consistent plagioclase composition (andesine No. 36-38); and by the consistent chemical composition of the rocks. This assimilation appears to have been helped by a degree of differentiation already achieved in the original melt, at the time of intrusion. This is suggested by the assemblage of accessory minerals and their volatiles common to both basic and acid magmas.

According to A. Ye. Fersman [15], the main properties of alkalic melts are their oxidation tendency, desilication, and rise in cation alkalinity (excess of alkaline cations). The sub-alkalic traprocks under study satisfy these requirements. Their Fe₂O₃/FeO = 0.76, while it is 0.2 in standard traprocks, and down to

Table 1
Data on Spectrographic Analysis of Subalkalic Traps, the Surrounding Unaltered Rocks and the Replaced Rocks Around the Ores²

Elements	Subalkalic dolerites										Leucodolomite spec. 123/56	Quartz Microdiabase Bors R. area spec. 44/56
	Korshunikhha deposit					Bol'shaya Boruch'ya R.			Chona R.			
	spec. 156/57	spec. 159/57	spec. 160/57	spec. 167/57	spec. 171/57	spec. 175/57	spec. 135-a	spec. 6/50	Namana R.			
Li	0.0n	0.0n	0.0n-	0.0n+	0.0n	0.0n	0.0n	0.00n	0.00n	n+	n-	-
Na	n-	n+	n+	n+	n+	n+	n+	n-	n-	n	n+	n-
Mg	n+	n+	n+	n+	n+	n+	n+	n-	n-	n+	n+	n+
Ca	0.0n-	0.0n-	0.0n+	0.0n+	0.0n	0.0n-	0.0n-	~0.1	0.0n	0.0n	0.0n-	0.0n-
Sr	0.0n+	0.0n+	0.0n+	0.0n+	0.0n	0.0n-	0.0n-	~0.1	0.0n	0.0n	0.0n-	0.0n-
Ba	n+	n+	n+	n+	n+	n+	n+	n-	n-	n+	n+	n+
Al	n+	n+	n+	n+	n+	n+	n+	n-	n-	n+	n+	n+
Si	n-	n-	n-	n-	n-	n-	n-	n-	n-	n+	n+	n+
Ti	0.0n	0.0n	0.0n+	0.0n+	0.0n+	0.0n+	0.0n+	0.0n+	0.0n+	0.0n+	0.0n+	0.0n+
V	0.00n	0.00n	0.00n+	0.00n+	0.00n+	0.00n+	0.00n+	0.00n+	0.00n	0.0n	0.0n	0.1
Cr	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-
Mn	n+	n+	n+	n+	n+	n+	n+	n+	n+	n+	n+	n+
Fe	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n
Co	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n	0.00n	0.01
Ni	~0.01	~0.01	0.054 ¹	0.021 ¹	0.039 ¹	0.041	0.031	0.281	0.00n	0.00n	0.00n	0.00n
Cu	—	—	—	—	—	—	—	—	—	—	—	—
Zn	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n
Ag	—	—	—	—	—	—	—	—	—	—	—	—
Ga	—	—	—	—	—	—	—	—	—	—	—	—
Pb	—	—	—	—	—	—	—	—	—	—	—	—
Be	—	—	—	—	—	—	—	—	—	—	—	—
Mo	—	—	—	—	—	—	—	—	—	—	—	—
Sn	—	—	—	—	—	—	—	—	—	—	—	—
W	0.00n+	0.00n+	0.00n+	0.00n+	0.00n	0.00n-	0.00n+	0.00n+	0.0n	0.0n	0.0n	0.0n
Zr	—	—	—	—	—	—	—	—	—	—	—	—
Se	—	—	—	—	—	—	—	—	—	—	—	—
P	—	—	—	—	—	—	—	—	—	—	—	—
K	n	n	n	n	n	n	n	n	n	n	n	n
	0.0n-	0.0n-	0.0n+	0.00n+	0.00n+	0.00n-	0.00n-	0.00n-	0.0n	0.0n	0.0n	0.0n

Table 1 (continued)

Ele- ments Borus R. area	Altered rocks around ores						Unaltered surrounding rocks					
	actinolitized, skarn-like rocks			chloritized and marble limestones			chloritized and garnetized cal- careous limestones.			dolomitized lime-stone		
	Korshunikha area	Deposits of the Nepskaya group	Dirin- Yurakh deposit	Daban deposit	Biryuk deposit	Dirin- Biryuk deposit	Daban, Borus	Dirin- Biryuk, Biryuk	Korshunikha deposit	Nepskaya group of deposits		
Li	0.000n—	0.000n—	0.000n+	0.00n—	0.00n—	~0.1	0.00n—	—	0.000n—	0.000n—	0.00n—	0.00n—
Na	n—	0.n—	~0.1	n+	n+	n—	n+	n+	n+	n+	n+	—
Mg	n+	n+	n+	n+	n+	n—	n+	n+	n+	n+	n+	n+
Ca	0.0n—	0.n+	0.0n—	0.0n+	0.0n+	0.0n—	0.0n+	0.0n—	0.0n+	0.0n—	0.0n—	0.0n—
Sr	0.00n+	—	—	—	—	—	—	—	—	—	—	—
Ba	—	—	—	—	—	—	—	—	—	—	—	—
Al	n—	n—	n—	n+	n+	n—	n+	n—	n+	n—	n—	~1
Si	n+	n	n	n	n	n—	n+	n	n	n	n	n+
Ti	n—	0.n—	~0.01	0.00n+	0.00n+	0.0n—	0.0n—	0.0n	0.n—	0.n—	0.n—	0.n—
V	0.0n—	0.00n+	0.00n—	0.03	0.00n	0.00n—	0.00n+	—	~0.01	~0.001	~0.001	~0.01
Cr	0.00n—	—	—	—	—	—	—	—	—	—	—	—
Mn	0.n	0.n	~0.1	0.n+	0.n+	0.n—	0.n+	0.n—	0.00n	0.0n—	~0.1	0.n
Fe	n+	n+	n+	n+	n+	n—	n+	n—	0.n	0.n—	0.n—	0.n+
Co	0.00n+	0.00n—	0.00n—	0.00n—	0.00n+	0.00n—	0.00n+	0.00n—	0.00n—	0.00n—	0.00n—	—
Ni	0.00n+	0.00n—	0.00n—	0.00n—	0.00n+	0.00n—	0.00n+	0.00n—	0.00n—	0.00n—	0.00n—	—
Cu	0.00n+	0.00n—	0.00n—	0.00n—	0.00n+	0.00n—	0.00n+	0.00n—	0.00n—	0.00n—	0.00n—	—
Zn	0.n—	?	0.0n+	0.0n+	0.0n—	0.0n—	0.0n+	0.0n—	0.00n	0.00n	0.00n	0.00n
Ag	—	—	—	—	0.000n	—	—	—	—	—	—	—
Ga	0.00n+	0.00n	0.00n	0.00n—	0.00n—	0.0n—	0.00n—	0.00n—	0.00n+	0.00n—	0.00n—	~0.001
Pb	0.00n+	0.00n	—	—	—	0.0n—	0.00n+	—	—	—	—	—
Be	0.000n	0.000n—	—	—	—	0.00n—	0.000n—	—	—	—	—	—
Mo	0.000n—	0.000n—	—	—	—	0.00n—	0.000n	0.000n+	—	—	—	—
Sn	0.00n—	—	—	—	—	0.00n—	0.00n—	0.00n—	—	—	—	—
W	—	—	—	—	—	0.00n	0.00n—	—	—	—	—	—
Zr	0.00n+	0.00n+	0.00n+	0.000n—	0.000n—	0.0n—	0.00n+	—	—	—	—	—
Se	—	—	—	—	—	—	—	—	—	—	—	—
P	0.n+	0.n	~0.5	0.0n+	0.000n—	0.0n—	0.0n+	0.0n+	—	—	—	—
K	0.n	—	—	—	—	—	—	—	—	—	—	—
Rb	—	—	—	—	—	—	—	—	—	—	—	—

¹Determined by the Detizonov method in the laboratory of I.G.E.M. of the Academy of Sciences of the U.S.S.R. by analytical chemist A.I. Pokrovskaya.

²Spectrographic analyses were made in the spectrographic laboratory of I.G.E.M. of the Academy of Sciences of the U.S.S.R. by F.I. Suminaya, A.F. Novikova and others.

Table 2
Data on the Spectrographic Analysis of Accessory and Vein Magnetites

Element	Subalkaline traprock						Accessory titanomagnetite			Quartz-olivine diabase; Borus R.	Syenite porphyry; Sopka
	Korshunikhha deposit			Boil'shaya Botnobiya R.		Chona R.					
	160/57	159/57	169/57	156/57	167/57	171/57	175/57	135-a	6/50	238/57	138/58
Mg	n-	0.n+	0.n	n-	n+	n	0.n	0.n+	0.n+	0.n+	0.n+
Ca	0.n	0.n-	~1	0.n+	0.n-	0.n	0.n-	~1	0.n+	0.n+	0.n+
Al	n-	~1	0.n+	0.n+	0.n-	n+	0.n+	0.n+	~1	n-	0.n-
Si	0.0n+	0.n+	0.n+	0.n-	0.n+	n+	n-	0.n+	0.n+	0.n+	0.n+
Ti	~1	0.n+	0.n+	0.n-	0.n-	n	n-	n-	n-	n-	n-
V	0.n-	0.n-	0.00n-	0.00n-	0.n-	0.n	0.n-	0.n-	0.n-	0.n-	0.n-
Cr	—	—	—	0.00n-	0.00n-	0.00n	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-
Mn	0.0n	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-
Co	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	—	—	—	—	—	—
Ni	~0.01	0.00n-	0.00n-	0.00n-	0.00n-	0.00n	0.00n-	0.00n+	0.00n+	0.00n+	0.00n-
Cu	0.00n+	—	—	0.00n-	0.00n-	0.00n	0.00n-	0.00n+	0.00n+	0.00n+	0.00n-
Zn	—	—	—	0.0n-	0.0n-	0.0n	0.0n-	—	—	—	—
Ag	—	—	—	—	—	—	—	—	—	—	—
Mo	?	0.00062	?	0.00012	0.000n+	0.000n+	0.000n+	0.000n+	0.000n+	0.000n+	0.000n-
Ga	0.00n-	0.00n-	0.00n-	0.00n-	0.00n+	0.00n+	0.00n+	0.00n+	0.00n+	0.00n-	0.00n-

Table 2 (continued)

Element	Korshunikhha deposit			Nepskoye deposit			Daban deposit			Dirin-Yuryevskh deposit			Borus R. area			Biryuk deposit			Sopka area		
	162/57	163/57	165/57	166/57	981	610/57	119/56	200	239/57	8/56	32/56										
Mg	n-	n-	n-	n-	n+	n-	n+	n-	n-	n-	n-	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	
Ca	0.0n	0.n+	0.n+	0.n+	0.n+	0.n-	0.n-	0.n-	0.n-	0.n-	0.n-	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	
Al	0.n+	0.n+	0.n+	0.n+	0.n+	0.n-	0.n+	0.n+	0.n+	0.n-	0.n-	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	
Si	0.n	0.n	0.n	0.n	0.n	0.n	0.n	0.n	0.n	0.n	0.n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	
Ti	0.25*	0.0!	0.0!	0.0!	0.0!	0.0!	0.0!	0.0!	0.0!	0.0!	0.0!	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	
V	0.11*	0.0n+	0.0n+	0.0n+	0.0n+	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	
Cr	-	-	-	-	-	0.0n--	0.0n-	0.0n+	0.0n+	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	
Mn	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n-	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	0.0n	
Co	0.00n+	0.00n+	0.00n+	0.00n+	0.00n+	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	
Ni	~0.01	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	
Cu	0.00n-	~0.001	0.00n+	~0.001	0.00n+	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	
Zn	0.01*	—	—	—	—	0.0n+	0.0n+	0.0n+	0.0n+	0.0n+	0.0n+	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	
Ag	—	—	—	—	—	0.00005*	0.00005*	0.00005*	0.00005*	0.00005*	0.00005*	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	
Mo	0.000n+	?	?	?	?	0.00n-	0.00n+	0.00n+	0.00n+	0.00n+	0.00n+	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	0.00n	
Ga	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	0.00n-	—	—	—	—	—	—	—	—	—	

¹Determined by the Detitzonov method in the I.G.E.M. laboratory of the Academy of Sciences of the U.S.S.R. by analytical chemist A.I. Pokrovskaya.

²Determined by the chemical method in TsKhL I.G.E.M. of the Academy of Sciences of the U.S.S.R. by analytical chemist O.V. Krutitskaya.

³The content of TiO₂ and V₂O₅ were determined by the chemical method in TsKhL I.G.E.M. of the Academy of Sciences of the U.S.S.R. by D.A. Pchelintsev.

0.03 in picritic dolerites; their desilication is expressed in a 44 to 46% SiO₂ content, low even compared with standard traprocks; their alkalinity is indicated by a higher Na₂O + K₂O content of 4 to 5%, while it is seldom over 2% in the normal series traprocks, as well as by higher values of stronger cations (CaO and MgO) with their alkaline properties.

This higher alkalinity of a melt is achieved by limestone assimilation at adequate depths.

Chemical and X-ray studies of vein rocks in all these deposits show that they all, although formed under somewhat different geologic conditions, are magnesium-magnetites (Mg, Fe) Fe₂O₄, thus demonstrating their affinity to a basic rather than an acid magma.

We differentiate these deposits, by their new mineral formations and by the composition of vein ores, into two main types:

1. High-temperature, containing pyroxene (of the diopside-hedenbergite series), garnet (grossularite-andradite), and magnesium-magnetite, with a small amount of the magnesium-ferritic component (MgFe₂O₄ = 0 to 7%).⁷

2. Low-temperature, marked by a development of calcite, chlorite, serpentine, quartz, magnesite, and magnesium-magnetite, with a large amount of the magnesium-ferritic component (MgFe₂O₄ ~ 80%).

The first type (Angara-Ilim and Nepa groups) is obviously related to comparatively shallow traprock bodies (hearths), while the second type (Daban, Biryuk) lie at a considerable distance away.

Thus the magnesium content of magnetite is a geologic thermometer recording the formation temperature of a deposit and its distance from a magmatic source.

RECOMMENDATIONS

The following operations are necessary in the search for iron-ore deposits.

1. Detailed exploration (geologic, magnetometric) in major zones of crushing, especially along two fault trends: northeastern and northwestern. Among prospective areas may be the junctions of dissimilar structures (of the first, second, and third orders) and domal structures with their higher intensity of disturbance. Volcanic vents are preferential emanation channels and should be looked for in zones of crushing.

Their occurrence in relatively homogeneous carbonate rocks facilitates their search.

A leading exploration criterion for iron-ore deposits is provided by the presence of sub-alkalic traprock and metasomatites with diopside, aegirine-augite, and black to brown garnet, i. e., andradite (melanite).

2. A detailed study of mineralogic, petrographic, and geochemical features of traprocks with the aim of discovering differentiated (particularly sub-alkalic) traprock varieties which may be associated with magnetite deposits.

Index accessory and secondary minerals of sub-alkalic traprocks as a source of iron mineralization are chlorine and fluorine-bearing apatite (from tenths to 5% and over), as well as higher-than-the-average amounts of pyrite, andradite, sphene, and titanomagnetite (with the magnetite component higher than the ilmenite), in the presence of fluorite, galena, zircon, biotite, hornblende, epidote, and occasional topaz. Typical of the altered near-ore rocks are also andradite, pyrite, apatite, molybdenite, epidote, K-feldspar, biotite, hornblende, with less common rutile and fluorite. Index minor elements in sub-alkalic traprocks and contact-metamorphosed rocks are Li, Be, Pb, and Mo. The geochemical affinity of accessory titanomagnetite from traprocks and from vein ores (Cu, Zn, Ga, and Mo present in both) is another evidence of their genetic relationship and of the endogenetic nature of the magnetite mineralization.

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⁷For the alkalic syenites, according to R. Daly (1933), Fe₂O₃:FeO = 1.0.

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Received, 28 May 1959

BRIEF COMMUNICATIONS

THE TARKHANIAN STRATUM IN THE WESTERN KOPET-DAG OF TURKMENIA¹

by

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The Tarkhanian stratum was discovered for the first time in the territory of Turkmenia in the north of the Krasnovodsk Peninsula [4]. The Tarkhanian deposits included the series of yellowish-brown and greenish-gray calcareous shales some 20 m thick, containing scales and teeth of fish, as well as shells of Pseudoamussium sp. These clay rocks are separated from the Oligocene clays underlying them by a sharp boundary, which shows traces of erosion of the latter [5].

Up to the present these deposits have been the single known occurrence of the Tarkhanian stratum in Turkmenia.

Investigators do not mention the presence of the Tarkhanian stratum within the Kopet-Dag, where outcrops of Middle and Upper Miocene deposits have been known for a long time. There are merely some citations of descriptions of the Chokrakian stratum as the oldest of the Middle Miocene deposits known within the Kopet-Dag.

The suggestion has been made that if the Tarkhanian Sea penetrated into the territory of the Kopet-Dag, it cannot have been far to the east, but must have been limited to the western part of the Kopet-Dag depression [2]. This supposition has been confirmed by our work.

In the summer of 1959, while studying the mode of occurrence of the Neogene deposits over the Paleogene, we established the presence of Tarkhanian beds in the western spurs of the Kopet-Dag. These deposits were identified by us quite reliably in two sections — at Mts. Geok-Oba and Kalendzha — the westernmost surface outcrops of Miocene rocks.

At Mt. Geok-Oba the Tarkhanian stratum overlies, without any visible unconformity, the dark-brown non-calcareous clays of Maykopian age, and is represented by the following layers:

- 1) brown siltstones, calcareous, with thin interlayers (about 1.0 - 0.2 cm) of gypsum, with a total thickness of 0.2 m;
- 2) dark-green, silty, calcareous clays, some 0.1 m thick;
- 3) greenish brown, calcareous, gypsumiferous clays, some 0.1 m thick.

This section, whose total thickness is only some 0.5 m, contains numerous fauna.

Among the macrofauna we have identified: Amussium (Pseudoamussium) denudatum Reuss., Aporrhais pes-pellicani (Linne), Abra alba Wood var., and Natica cf. helicina Bross. The microfauna are represented by various foraminifer species: Sigmeilina tenuis (Gzjzek), S. mediterranensis Bogd., Miliolina aff. boueana Orb., M. aff. selene (Karrer)., M. austriaca Orb., M. Ungeriana Globigerina tarchanensis Subb. et Chtr., Entoscelinea sp., Nodosaria sp., Cristularia sp., Nonion boueanus Orb., Bolivina tarchanensis Sub. et Chtz., B. ex gr. floridana Cushman., Neobulimina aff. elongata Orb., Cassidulinoides tarchanensis Chutz. var. nov. (Volosch.), Streblus beccarii (Linne), Globigerina sp., and Textularia tarchannensis Bogd. There are also spiraliales, embryonic pelecypods and columnals of amphurians and ooliths; the latter include Otolithus (Clupea) tarchanicus Pobedina, O. (Gobius) aff. rotundus var. tarchanensis Pobedina, and O. (Gobius) aff. rotundus Pobedina.

The half-meter packet of Tarkhanian deposits with its abundant content of fauna merges in a gradual transition with the overlying yellowish-green clays and siltstones, containing a Spirialis fauna in their lower part (about 3 m). No other fauna has been found in these clays and siltstones. The thickness of the clay-siltstone packet is 14 m.

¹Tarkhanskiy gorizont zapadnogo kopet-daga Turkmenii.

The clay-siltstone packet is overlain by a 70-meter thick stratum of barren green clays, at the top of which is a limestone-layer with a Chokrakian fauna consisting of Donax tarchanensis Andrus. and Frvilia praepodolica Andrus.

The section through the Tarkhanian beds at Mt. Kalendzha resembles that described above. The Tarkhanian beds here lie upon Maykopian shales; the contact between them is of the same nature as at Mt. Geok-Oba.

Above the Maykopian clays here there are:

- 1) white gypsum, 0.03 - 0.05 m thick;
- 2) dark green, calcareous clay, 0.2 m thick;
- 3) pinkish-gray, calcareous clay, 0.15 m thick;
- 4) green, calcareous clay, 0.1 m thick.

The deposits contain an abundant fauna: Amussium (Pseudomussium) denudatum Reuss., Abra cf. parabilis Zhizh., Aporrhais pespellicani Linne, Natica helicina Bross., Turbonilla ex gr. grevis Reuss., Nassa cf. tamenensis David., N. cf. rusticorum David., Nassa restitutiana Font. The foraminifera are represented by Sigmoilina tenuis (Czjzek.), S. mediterranensis Bogd., Miliolina-consobrina (Orb.), M. selene (Karrer.), Globigerina tarchanensis Subb. et Chutz., Entoselenia sp.,

Nodosaria sp., Cristelaria sp., Nonion boueanus (Orb.), Bolivina tarchanensis Subb. et Chutz., B. aff. floridana Cushman., Neobulimina aff. elongata Orb., Cibicides lobatulus (Walker et Jacob).

Among the ostracodes L. P. Markova has identified: Loxoconcha ex gr. carinata Lichen., Loxoconcha sp., Cytheridia muelleri (Munst.), Trachyleberis dromas Schneider. There were also specimens of Spirialis, pelecypod and gastropod embryos, and fragments of echinoderms (amphiurians).

As at Mt. Geok-Oba, this half-meter packet with its abundant fauna is covered by yellowish green clays and siltstones containing a Spirialis fauna in the lower part. Other fauna have not been found. The shale-siltstone packet is some 15 m thick.

In the overlying chocolate-colored, non-calcareous clays (5 m thick) and the yellowish green calcareous siltstones (5 m thick) that lie above the latter clays, fauna is also lacking. Only in the gray sandstones occurring next above is there a Chokrakian fauna, consisting of Chlamys pertinax (Zhizh.) and Chama toulai David.

The faunal assemblage described above, by analogy with the fauna of the Crimean-Caucasus region, places the half-meter packet of Tarkhanian deposits at Mts. Geok-Oba and

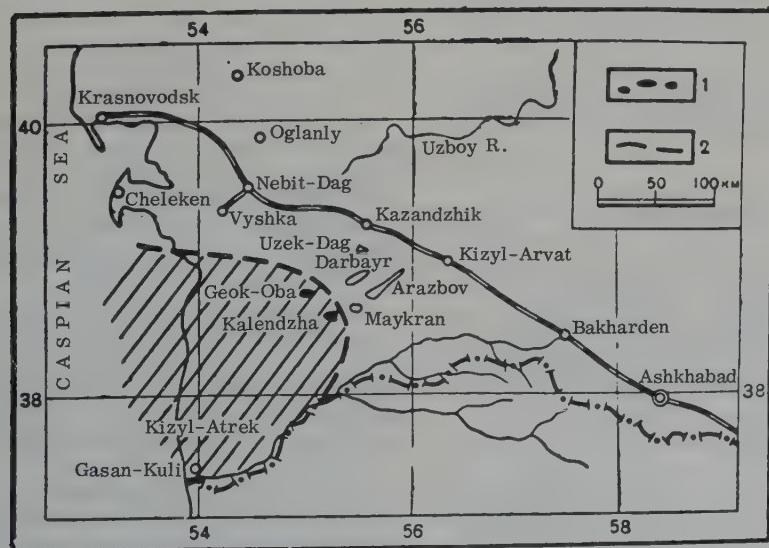


FIGURE 1. Diagram of the supposed distribution of the Tarkhan deposits within Southwestern Turkmenia:

1 - sections in which the presence of Tarkhanian deposits has been established; 2 - inferred boundary of the area of distribution of the Tarkhanian deposits.

Kalendzha within the Terskiye beds. The lower part (3 m), in accordance with the overlying Terskiye clays and siltstones containing Spirialis fauna, must in all likelihood be considered the analogue of the Argunian beds in the Crimean-Caucasus region [1]. The deposits occurring above these three meters (the 70-meter stratum of clays at Geok-Oba and the packet of clays and siltstones at Kalendzha) apparently belong to the Chokrakian level, which conformably overlies the Tarkhanian deposits.

In the sections through the Miocene of the Kopet-Dagh, located east of Mts. Geok-Oba and Kalendzha, the Tarkhanian stratum is absent, and the Maykopian shales are overlain directly by Chokrakian deposits (Mts. Maykran, Arazdov, Uzek-Dagh, Darbayr and others). This circumstance suggests that the Tarkhanian sea did not extend to these regions, and that its shoreline lay to the west of them (Figure 1).

CONCLUSIONS

1. The presence of a faunally characterized Tarkhanian stratum has been established within the Western Kopet-Dagh mountains.

2. By analogy with the Crimean-Caucasus region, Terskian beds have been definitely and Argunian beds tentatively distinguished within the Tarkhanian deposits.

3. The thickness of the Terskian beds is 0.5 m, and that of the Argunian beds is about 3 m.

4. On the basis of the occurrences of the Tarkhanian deposits, the supposed boundary of their distribution has been drawn within Southwestern Turkmenia.

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Received, 8 October 1959

PETROGRAPHIC FEATURES OF COALS FROM THE LVOV-VOLYNIA BASIN²

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(Deceased)

The Lvov-Volynia coal basin is associated with the Lvov-Brest marginal trough of the Russian platform, whose axis, according to geophysical data, passes along the Gorodok-Rava Russkaya line, west of Brest. Its eastern slope lies in the U. S. S. R.; the remainder in the Polish Peoples' Republic.

A longitudinal fault passing north of Vladimir-Volynsk bisects the folded system of the Lvov-Brest trough east slope into two blocks: the Volyn-Brest uplift in the north and a lower block of the Lvov-Volynia trough in the south with its coal measures spared by the subsequent erosion.

Tectonically, the Lvov-Volynia trough is comparatively simple. Traceable on the background of a flat westerly regional dip (2 to 3°) are two groups of folds: one trending slightly north of east-west, and the other slightly north-east.

² Petrograficheskiye osobennosti ugley l'vovsko-volynskogo basseyna.

The crests of latitudinal folds are eroded and the entire coal area is broken up into segments known as the Volynian, Sokal, Mezhrech'ye, and Zabuzh'ye.

This basin is closed because its coal measures are buried under Mesozoic and Cenozoic deposits, from 350 m thick in Volynia to 550 m in Mezhrech'ye. The coal accumulation started in the Viséan and continued in the Namurian and Lower Westphalian.

The Viséan, represented by marine deposits, changes upward to terrigenous facies including up to 25 coal seams, of workable thicknesses up to 0.5 m in very restricted areas. The Bus twin seam and the Bubnov are among such coal beds.

Namurian deposits are differentiated into a lower barren interval and an upper, coal-bearing, formed by deltaic sediments with lagunal-marine intercalations.

Conditions favorable for accumulation and preservation of plant material prevailed in Upper Namurian time over the entire basin, resulting in 22 coal seams with 2 to 7 among them of workable thickness (0.6 to 1.7 m). Westphalian deposits are developed along the western margin of the Zabuzh'ye and Volynia deposits where they are represented by terrigenous clastic rocks with beds of coal, carbonaceous shale, and occasional limestone. Only four out of the ten coal seams are workable, and that over a restricted area.

In their metamorphism, the Namurian coals, the basis of mining, belong to Mark D-G, in Volynia, changing to Mark G-PZh farther south (Mezhrech'ye Mine, No. 2), and then to Mark K at the Polish border.

1. Petrographic Composition and Structure of Coal Seams

One of the basic factors determining the structure and petrography of a coal bed is the paleogeographic environment of the deposition and decomposition of plant material.

D.P. Bobrovnik [2], in his study of Namurian-Westphalian facies, determined that the Lvov-Volynia basin had been formed during a steady migration of the coast line. This is what has determined the complex structure of its coal beds, both areally and vertically.

Of the numerous Namurian coal beds, only p_7^n , p_7 , p_7^V , p_8 , and p_8^V are workable, with p_7^n the lowest, and workable only locally in the Mezhrech'ye deposit. This seam is simple in structure and attains 1.7 m. Its coals are derived from banded humus, with an alternation of dull and lustrous types persisting in fairly

thick layers over 6 to 8 km. Its lower member, up to 0.6 m thick, is sapropelitic.

Seam p_7 (Volynsk I) maintains its working thickness of 0.5 to 1.22 m in the central part of the Volynsk deposit and in individual areas of the Zabysh'ye and Mezhdurech'ye. Its structure is simple only in the southern Zabuzh'ye (Trans-Bug); in parts of Volynia, it is split into 2 to 5 members. Its coals are derived from humus, banded, quite inconsistent in petrography. In Volynia, it is represented largely by dull fusains, 3 to 30 cm in thickness, and easily traceable over the entire deposit.

In the Mezhrech'ye deposit, this seam is almost free of fusain and is represented largely by durain (Mine No. 2). In the south (Mine No. 4), this seam is almost completely made up of lustrous coals.

Seam p_7^V is developed everywhere but is of a workable thickness only in isolated areas. It is unworkable in Volynia, while attaining workable thicknesses of 0.8 to 1.6 m in the south, in Mezhrech'ye and in the southern part of Zabush'ye and Sokal. Its humus coals are locally fully replaced by sapropelitic, boghead-cannel, and boghead (Sokal deposit coal). The p_8 (Volynsk II) seam is consistently workable and simple in structure, except for Mezhrech'ye where it consists of an upper sapropelitic member and a lower humus member, separated by 0.75 m of shale. The sapropelitic member thickens up in many places from 0.15 to 0.75 m, to become workable, besides the main workable humus member. The lower member (the main workable one) has a simple structure and ranges in thickness from 0.05 to 0.80 m.

This seam has a simple structure within the Sokal and Volynsk deposits, where it is 0.60 to 1.60 m thick. Its humus coals are banded throughout the area.

Coal bed p_8^V is workable in the southern part of Mezhrech'ye, in Zabuzh'ye, and in northern Sokal. It is not workable in Volynia. It consists of two to four humus members, with the lower locally represented by sapropelite. The humus coal presents an alternation of dull and semi-lustrous varieties; the sapropelitic is cannel or boghead-cannel coal.

Coal petrographic analyses have established that the source material consists of higher land plants which have produced the humus coal, as well as algae — the source of sapropelitic coals.

Humus coals of this basin are banded because of a rapid alternation of lustrous, dull, semi-dull, and semi-lustrous types whose origin is related to changes in the water level caused by bottom oscillations and by a seasonal alternation of rainy and dry periods.

Table 1

Quantitative Relationships of the Petrographic Types of Coals in the Seams,
by Deposits (Based on the Averaged Data on Samples Taken from the Mines)

Deposit	Index of coal seam	Sapropelite content in seam, in %	Contents of types of humic coals, in %				
			bright (ultra-clarain and clarain)	semibright (duro-clarain)	semidull (claro-durain)	dull	
			durain	fusain			
Mezhrech'ye	n_7^H	12	15	15	—	55	15
Volynsk	n_7	—	10	30	18	7	35
Zabuzh'ye	"	—	35	20	35	7	3
Mezhrech'ye	"	—	70	25	—	2	3
Zabuzh'ye	n_7^B	10	8	18	18	50	6
Mezhrech'ye	"	5	7	17	16	55	5
Volynsk	n_8	—	30	15	33	12	10
Zabuzh'ye	"	—	22	25	34	11	8
Mezhrech'ye	"	30	25	15	42	15	3
"	n_8^B	10	7	15	5	65	8

As shown in Table 1, seam p_7^H is made up of dull durain with a smaller amount of lustrous clarain.

Seam p_7 , in the northern part of the basin, consists mostly of fusain and semi-lustrous coals. To the south in Zabuzh'ye and then in Mezhrech'ye, this seam becomes richer in lustrous coals, with a sharp drop in dull fusain content.

Seam p_7^V is virtually uniform in composition everywhere, being represented mostly by durain.

Seam p_8 is made up of lustrous, semi-lustrous, and semi-dull coals, virtually uniform throughout the area. In the southern part of Mezhrech'ye, it is somewhat richer in dull coal and carries a sapropelite member (Mine No. 4).

Seam p_7 is represented largely by dull coals with a small amount of lustrous coals.

The inconsistent petrography of coal beds throughout the area points to different conditions of formation.

2. The Effect of Petrographic Composition on the Chemical Properties of Coals

To determine the relationship between chemical properties of coals and their petrographic composition, we tested the principal seams from operating mines of the basins and

from those under construction. Only the humus members without sapropelites were tested. Their petrographic composition was determined by counting their microcomponents in briquets immersed in oil, under reflected light. It turned out that seams p_7^V , p_8 , and p_8^V have the same microcomponent ratio throughout the area.

Seam p_7 is quite similar petrographically to these seams, in the Mezhrech'ye deposit; in Volynia, it differs from all others in having a low content of baking components.

In Volynia, as tested in mine samples, seam p_7 carries 52 to 63% baking components represented by vitrinite + leiptinite. In the same samples, the total fusain content is 29 to 42%. In the south, in Mine No. 2, Mezhrech'ye, seam p_7 has a quite different petrographic composition characterized by a high content of baking components (91%), with the vitrinite content increasing up to 82%; leiptinite, up to 9%; while that of fusinite is sharply reduced to 6% of the total coal.

Changes in the petrographic composition of coals are clearly reflected in their chemical and technological properties: while the output of volatiles is 29 or 30% of the total combustible volume of seam p_7 , in Volynia, it is 4% higher in Mezhrech'ye Mine No. 2. This increase can be explained by a higher spore content.

Consequently, the lower volatile content in seam p_7 , in Volynia, is explained by a low content of cutinized elements and a higher amount of fusain.

Table 2

Petrographic Microcomponent Composition of the Coal Seams, by Deposits

Deposit	Drill hole or mine	Seam	Vitrinite	Leiptinite	Vitrin- ite + Leiptin- ite (v_t + a)	Fusinite	Mineral admixture + pyrite ¹
		Sample	(v_t)	(a)	(v_t + a)		
Volynsk	Mine 1 (drift of the southern hauling stope)	$n_7/1$	58.0	5.0	63.0	29.0	8.0 (3)
	Mine 2 (second northern wall)	$n_7/2$	49.0	3.0	52.0	42.0	6.0 (4)
	Mine 2 (ventilation shaft)	$n_7/1$	49.0	6.0	55.0	40.0	5.0 (3)
	Mine 3 (second northern wall)	$n_7/1$	58.0	4.0	62.0	30.0	8.0 (4)
	Mine 2 (second northern wall)	$n_8/2$	78.0	10.0	88.0	10.0	2.0 (0.5)
	Mine 3 (upper wall)	$n_8/3$	78.0	8.0	86.0	11.4	2.6 (0.6)
Mezhrech'ye	Mine 2 (hoist shaft)	$n_7/1$	82.0	9.0	91.0	6.0	3.0 (0.5)
	"	$n_7^B/1$	74.0	10.0	84.0	8.0	8.0 (3.0)
	"	$n_8/1$	81.0	10.0	91.0	5.8	3.2 (0.5)
	"	$n_8^B/1$	72.0	12.0	84.0	8.0	8.0 (4)
Zabuzh'ye	Drill hole 1516	n_8	85.0	12.0	97.0	3.0	3.0 (0.5)
	Drill hole 1554	n_8	78.0	10.0	88.0	10.0	2.0 (0.5)
Sokal'skoye	Drill hole 523	n_8^B	64.0	18.0	82.0	12.0	6.0 (5)
	Drill hole 586	n_8	82.0	11.0	93.0	5.0	2.0 (0.1)

¹Pyrite content given in parentheses.

Petrographically, seam p_8 is quite different from the underlying seam p_7 in its higher content of the vitrinite and leiptinite components (86 to 88%) and in a comparatively small addition of fusinite (10 to 11%); as a consequence, it carried 7% less volatiles than seam p_7 .

In the Mezhrech'ye deposit, seams p_7 and p_8 , opened by a shaft of Mine No. 2, are very similar in their ratios of vitrinite and fusinite groups and are characterized by a high content of the leiptinite group components. They are also similar in their volatile content (30 to 33); a comparison shows a 5% reduction in volatiles of seam n_8 , in Mezhrech'ye compared with Volynia; with the same petrographic composition, this means a higher-grade metamorphism of the coals.

The carbon content in seam p_7 in Volynia is 81.2% with 4.95% hydrogen; in Mezhrech'ye, there is 3% less carbon and 2% more hydrogen.

Its volatile content, too, rises in Mezhrech'ye, where it is 33.5% compared to 20 or 30% in Volynia. On the basis of chemical properties alone, one can conclude erroneously a northerly rise in grade of metamorphism toward Volynia; as a matter of fact, the change in these properties is not related to metamorphism but rather to the petrographic composition of seam p_7 enriched in fusinite, which gives it the properties of lean coals.

Thus, a correct solution of the problem of the rank of coals from the Lvov-Volynia basin and of their industrial use lies not in a chemical analysis alone, but in the ratio of their petrographic components.

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L'vov

Received, 1 June 1959

LOSSES TO SCIENCE

by

V. V. Tikhomirov, and E. A. Kupcha

Strashimir Dimitrov, Vice-President of the Bulgarian Academy of Sciences, and Director of its Geological Institute, died April 26, 1960, in Prague. He was an outstanding expert on the geology of the Balkans.

S. Dimitrov was born in Sofia, August 23, 1892, graduated from the Department of Natural Sciences at Sofia University in 1914, and was appointed assistant in Physics and Mathematics at the Mineral-Petrographic Institute in 1920; Associate Professor in 1937; and Professor in 1941. In 1927-1928 he specialized in petrography at Heidelberg, Germany. He was elected Active Member of the Bulgarian Academy of Sciences in 1947; Academic Secretary of its Section of Geologic, Geographic, and Chemical Sciences, and Director of its Geological Institute; in 1959 he became its Vice-President.

The main works of S. Dimitrov are in the field of petrography, mineralogy, and industrial minerals of Bulgaria. He did much to advance the study of intrusive and metamorphic rocks and associated mineralization; a number of his works are regional in scope and contain the results of his mapping. After the foundation of the Bulgarian People's Republic, S. Dimitrov actively participated in the engineering geologic study of regions of large hydrotechnical and industrial construction.

He is the author of a number of texts in petrography and mineralogy and of many popular science articles in geology.

He was awarded the Dimitrov Prize, First Class; the Order of the People's Republic of Bulgaria, First Class; and the Civic Merit Order, First Class.

* * *

Mikhail Mikhaylovich Konstantinov, Candidate in Geologic and Mineralogic Sciences, Member of the C. P. S. S. since 1930, and an outstanding expert in the geology of non-ferrous and rare metal deposits, died January 19, 1960.

He was born in Irkutsk, July 8 (June 24), 1907, to the family of a professional revolutionary. In 1931 he graduated from the Moscow Geologic Exploration Institute and worked for a long time in Siberia, Trans-Baykal, the Far East, and the Caucasus. Up to 1947, he worked in the administrative branch of the Ministry of Non-Ferrous Metallurgy, U. S. S. R. Between 1947 and 1956, he was Senior Scientist and Section Chief at the All-Union Institute of Mineral Raw Materials and later on was Academic Editor for the Main Administration of the Atomic Energy Press, at the Council of Ministers, U. S. S. R.

The principal works of M. M. Konstantinov are in the field of geology of lead, zinc, uranium, and other non-ferrous and rare metal deposits. He developed in his publication original ideas on the origin of this mineralization in sedimentary rocks, in the process of diagenesis and metamorphism.

Very valuable is his monograph (in collaboration with Ye. Ya. Kulikova) "Uranium Provinces" (1960), citing and critically analyzing data extant on the geology of uranium deposits and describing the most important features of uranium provinces of the world.

M. M. Konstantinov took an active part in the work of many special commissions on evaluation of many mineral deposits of the U. S. S. R. and the people's democratic countries; he was one of the organizers of the non-ferrous metal industry in our country. He was awarded three medals of the Soviet Union.

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Ludmila Petrovna Monakhova, Candidate Geol. -Min. Sc. and Senior Assistant in the Laboratory of Coal Geology at the U. S. S. R. Academy of Sciences, passed away on April 23, 1960. She was born January 15, 1922, at Tashkent; graduated in 1947 from the Leningrad Mining Institute, majoring in geologic surveying and exploration; and in 1951 defended her thesis for the candidacy, "Brachiopod Fauna from the Ashlyark Formation, the Karaganda Coal Measures".

L. P. Monakhova's studies were on the Lower Carboniferous stratigraphy of Central Kazakhstan; she was an expert on the Carboniferous brachiopod fauna; in her last years she also studied goniatites. For a number of years, she was in charge of the Paleontologic Section of the Coal Geology Laboratory and participated in compiling the exploration map of the U. S. S. R.

* * *

Senior Scientist at the Geological and Geophysical Institute, the Siberian Affiliate of the U. S. S. R., Academy of Sciences, Aleksey Borisovich Travin, Candidate Geol. -Min. Sc. and an expert on coal deposits of Siberia, died on May 8, 1960.

A. B. Travin was born January 24 (11) 1908, in Tomsk, and graduated in 1941 from the Geologic Exploration Department at Tomsk Industrial Institute. His main work was in coal petrography. He studied metamorphism of Kuzbas coals; outlined the connection between their germanium concentration, petrographic composition, facies conditions, and the tectonics of the coal measures; he proposed a theoretical explanation for the germanium concentration in the coals; and he worked out a classification and nomenclature of coal micro-components.

He participated in the Great Patriotic War and was awarded two medals.

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Professor of geology and physical geography at Biya Teachers Institute, Frederic Wilhelmovich Lungerhausen, passed away on May 11, 1960. He was born May 12 (April 30), 1884, at the village of Bekovo, Saratovskaya Guberniya. In 1909, he graduated from the Physico-Mathematical Department of Moscow University, majoring in geology, under A. P. Pavlov. Between 1908 and 1914 he worked as a geologist for the Zemstvo (Civic Land Organization), conducting geologic and hydrogeologic surveying in Tul'skaya, Yekaterinoslavskaya, and Tambovskaya guberniyas. In 1912, he became a teacher in Tambov, first at the Gymnasium and then, between 1918 and 1923, at the Teachers' and the Agricultural Institutes.

In 1923 and 1934, he was Professor at the Belorussian Agricultural Academy; from 1934 to 1941, at Saratov State Teachers Institute; and from 1941 on, at Biya Teachers' Institute. He began his geologic field work in 1907, in the Volga Region, central Russia, and Belorussia. He is the author of a text of geology and hydrogeology of the Belorussian S. S. R. and of articles on teaching methods. In 1937, F. W. Lungerhausen was granted the Candidate degree in geol. -min. sciences, without having to present a thesis. He was awarded the medal of Merit

In the Great Patriotic War. He retired on a pension in 1957.

* * *

Natal'ya Vasil'evna Frolova, Candidate in Geol. -Min. Sc., and an outstanding expert on metamorphism and geology of the most ancient Siberian rocks, passed away on July 18, 1960. For her obituary see Izvestiya Academy of Sciences, S. S. S. R., ser. geol., no. 9, 1960.

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Professor of the Toilers' Red Banner Novocherkassk Polytechnical Institute, Grigoriy Makedonovich Yefremov, Doctor Geol. -Min. Sc., died July 21, 1960.

He was born January 30, 1898; graduated from the Mining Department of Don Polytechnical Institute; and went to work for the North Caucasian Geologic Administration. In 1933 he became assistant; in 1938, Associate Professor; in 1953, Professor; and in 1954, Head of the Mineral Department at Novocherkassk Industrial (subsequently Polytechnical) Institute. He also was Dean of its Geologic Exploration Department, in 1953-1958.

The principal works of G. M. Yefremov were in the field of the geology and minerals of the North Caucasus, largely non-ferrous metals. Prominent in his works are structural studies of mining areas, of polymetallic mineralization, and of problems in metallogeny. Regularities discovered by him in the Sadon ore body were of importance in the forecasting, exploration, and discovery of other North Caucasian ore deposits.

* * *

Academician Nikolay Sergeyevich Shatskiy, an outstanding Soviet scientist, Laureate of the Lenin and Stalin Prizes, passed away on August 1, 1960. His works are a major contribution to various branches of geology. His obituary is published in Izvestiya Academy of Sciences, U. S. S. R., geol. series, no. 10, 1960.

* * *

Victor Arsen'yevich Nikolayev, Corresponding Member of the U. S. S. R. Academy of Sciences and Laureat of the Lenin Prize, died on September 25, 1960.

He was born December 6 (November 24) 1893, in Nizhniy Novgorod (now Gor'kiy). In 1918 he graduated from the Geologic Exploration Department of Petrograd Mining Institute and went to work in the Uralian (Zlatoust) and Kuzbas (Kemerovo) mines. In 1920 he became associated with the Geokom and then with the All-Union Geological Institute (VSEGEI). In

1924-1931 he became teacher and then Associate Professor at Leningrad Mining Institute, and Head of the Petrography Department, in 1947. Between 1933 and 1945 he was Professor at the Central Asian Industrial Institute; Honorary Scientist of the Kirghiz S. S. R. (1943); and President of the All-Union Mineralogic Society (from 1955 on).

V. A. Nikolayev studied alkalic rocks of Talas Alatau, ore deposits in Central Asia, volcanism of Tien-Shan, etc. In his studies of petrology, he ascribed great importance to the

liberation of magmatic volatiles and outlines the sequence of magmatic phenomena. Of great value are his studies of the principal regularities in the development of structural-facies zones in mobile crustal belts, and in the theory of magmatogenic ore deposits.

He was awarded the orders of Lenin, Toilers' Red Banner, Merit, and a medal.

Geological Institute, the U. S. S. R.
Academy of Sciences
Section of History of Geology

REVIEWS AND DISCUSSIONS

MONOGRAPHIC SERIES "THE ORDOVICIAN OF KAZAKHSTAN"¹

by

B. S. Sokolov

The Stratigraphy Section of the Geological Institute, the U. S. S. R. Academy of Sciences, has undertaken a number of stratigraphic and paleontologic research projects which long ago became its main field of activity. Outstanding among the published stratigraphic studies is a monographic series, "The Ordovician of Kazakhstan", already represented by three issues (1954, 1956, and 1958).

There are two reasons for the great importance of this work: its attempt to achieve a broad and comprehensive substantiation of the present Ordovician correlations for Kazakhstan, on the basis of a detailed study of type sections (particularly in the Chu-Ili Mountains) as well as analysis of most important faunal groups; and, secondly, for its convincing and incontrovertible thesis on the stratigraphic independence of the Ordovician as a system — a controversial subject, until recently, at the Geological Institute itself. In this connection, we can only welcome the introductory article by B. M. Keller who has inspired this series, on type Ordovician sections, in which the principles of correlation and subdivision of that system are set forth.

Turning to some results of this study, it should be noted at once that the Ordovician faunas of Kazakhstan and Central Asia are extremely peculiar. Even V. N. Weber [1], in his early work as far back as the 1930's, identified 80 or 90% new species of trilobites peculiar to the Kazakhstan Ordovician alone. Subsequent monographs on brachiopods, pelecypods, heliolitids, and other fossils, along with a further study of trilobites, have revealed the same ratios. Consequently, one

cannot disagree with the author that an Ordovician stratigraphic table for Kazakhstan, and its practical application, depend to a considerable degree on the status of local paleontologic material and on its correlation with Ordovician faunas elsewhere in the world.

The work already accomplished has advanced our knowledge of Kazakhstan Ordovician fossil assemblages greatly. Although only the trilobites were known earlier, we now have an idea of many other groups of fossils: graptolites (B. M. Keller, Issue I, 1954; II, 1956; A. M. Obut, II, 1956); brachiopods (T. B. Rukavishnikova, II, 1956); trilobites (K. A. Lisogor, I, 1954; M. P. Chugayeva, III, 1958); pelecypods (L. L. Khalfin, III, 1958); gastropods (V. A. Vostokov, II, 1956); nautiloids (Z. G. Balashov, II, 1956); Heliolitidae and Tabulata (O. B. Bondarenko, III, 1958). To be sure, such groups as conodonts, crinoids, bryozoa, stromatoporoids (except for a single species described by V. K. Khalfina, in III, 1958) have escaped authors' attention, as yet, but this gap will undoubtedly be filled, in time. What is important now, field geologists may count on substantially more detailed information on the age of Ordovician deposits in Kazakhstan, than that obtainable a few years ago. Without such data, even specially organized stratigraphic studies were doomed to failure, being considerably diminished in value because of the lack of monographic paleontologic literature.

Very fortunately, B. M. Keller used in his stratigraphic tabulations such important groups as graptolites. Findings of graptolites in Kazakhstan were known before [3]; at first, however, they were regarded as typical of the entire Ordovician. The fact is that the degree of their preservation is different at different horizons. It is rather poor in some beds (Kogashikh and Anderken), while in others the graptolites present splendid material for future paleontologic studies (Kopalin horizon in the Chu-Ili Mountains). B. M. Keller has succeeded in identifying the graptolite assemblages from various units and has made interesting stratigraphic inferences. The age of many stratigraphic divisions of the Kazakhstan section has

¹O serii rabot "Ordovik Kazakhstana".

been pinpointed, in this way, rather than by the use of the benthonic fauna, largely brachiopods and trilobites, as done in the past.

Results of the Chu-Ili brachiopod study are set forth in T. B. Rukavishnikova's work (II, 1956), carried out on a high scientific level, with a detailed description of the interior structure of shells. The author has identified the rich and diversified brachiopod assemblages typical of the Middle and Upper Ordovician. Quite unexpected was a parallel occurrence of representatives of genus *Plectatrypa* and forms similar to the Middle Ordovician genus *Nimella* (Dulankarin horizon), which enabled T. B. Rukavishnikova and other students to draw the Middle-Upper Ordovician boundary within that unit. This is not quite in accord with the results of the coral study (O. B. Bondarenko, III, 1958): their assemblages in both the Dulankarin and the underlying Otar horizons suggest rather the Upper Ordovician. Even more suggestive are the Dulankarin genera of the Heliolitida and Tabulata: their mass distribution rules out even the lowest Upper Ordovician for the Dulankarin; most probably, it belongs to the middle part of the Upper Ordovician.

Of interest are M. N. Chuguyeva's conclusions (III, 1958) on Ordovician trilobites. A detailed matching of generic assemblages with varying lithologies demonstrates a close relationship between them and different facies: it turns out that trilobite assemblages from limestones are different from those in arenaceous rocks. It has been determined that the "Llandeilo" assemblages from the Dulankarin horizon occur higher in the section than the Anderken limestone-type assemblages assigned to the top of the Ordovician, by V. N. Weber. This shows up the difficulties involved in dating the local horizons by trilobites, without a local stratigraphic standard, except that from remote sections of England and the Baltic Region.

There is no room in a brief article for a review of all works in this series; I want to emphasize, above all, its timeliness and the great theoretical and practical value of a further study of the Ordovician in Kazakhstan, middle Asia, and western China, in dating the rocks during mapping. It is particularly gratifying that the Geological Institute, in commissioning B. V. Keller to do this work, has transcended the purely "departmental" consideration for the cause, and called on outstanding experts from various organizations to do the study of the Kazakhstan Ordovician, thereby assuring a thorough analysis of nearly all paleontologic material. This is what has put the new stratigraphic scheme on a truly scientific basis.

In further studies of the Kazakhstan Ordovician, which are far from complete, especial attention should be given to hiatuses in this

section (especially the pre-Dakzhal, pre-Kopaln, pre-Anderken, etc.); to the study of new standard sections; and to the extension of faunal assemblages. That will enhance the correlation value of the new classification the uniformity of which is desirable.

Especially urgent is a publication of one of the most important, the fourth issue of this series, on Tremadoc deposits. This issue, prepared in 1957, has already been announced in the Academy prospectus. It is quite familiar to stratigraphers, but its publication has been postponed from year to year, for reasons unknown. Its prompt publication will be most welcome and will complete a major stage in the study of Ordovician stratigraphy of Kazakhstan.

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THE NATURE OF IJOLITE-MELTEIGITES²

by

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The problem of the ijolite-melteigite group became especially critical two years ago, after L. S. Borodin's article demonstrating the metasomatic nature of this group and defending (on that basis) the hypothesis of carbonatites formation from calcium liberated from pyroxenites during their nephelinization [1]. This concept has gained wide popularity among geologists and petrographers, the students of ultrabasic alkalic complexes. So far as can be judged from their works, the main criterion for a metasomatic origin is primarily microscopic study. Another attraction of L. S. Borodin's hypothesis was the simplicity of its explanation for the excess of calcium directly leading to the formation of carbonatites.

²O prirode iylitol-mel'teygitov.

L. S. Borodin's article provoked some criticism. Thus B. I. Serba [7] stated that the formation of carbonatites in such a way would require a tenfold volume of nephelinized pyroxenite, uncommon in nature. However, that objection is hardly valid. Indeed, we know only the area of a given section, and not its rock volume. Because of that, this specious reasoning is not convincing.

A substantial criticism was offered by N. A. Volotovskaya and A. A. Kukharenko [4]. Their arguments apparently are weighty enough for some petrographers; however, inasmuch as other petrographers recognize the process of pyroxenite nephelinization, a geologists unsophisticated in such refinement is left in the dark, the strength of Volotovskaya-Kukharenko's arguments notwithstanding.

It seems that this problem should be solved mainly by a study of the geologic environment: knowledge of the environment, alone, can determine the validity of other considerations. We shall attack this problem from that point of view, after two or three preliminary observations.

First, there is the nature of carbonatites. In considering the evolution of a magma, we are not likely to face the problem of a calcium deficiency. Indeed, beginning with the formation of peridotite, particularly pyroxenites, and up to the termination of magmatic differentiation, none of its products are low in calcium and magnesium. These elements are plentiful at all stages of this evolution. The difficulty lies in their reduced content after the pyroxenite crystallization. To be sure, a drop in their content in the residual melt can also be inferred, but it is just as probable that calcium (and magnesium, to a smaller extent) keeps accumulating in the residual melt, and is not precipitated as a solid phase (lack of plagioclase ?), until a much later change in conditions is favorable for its precipitation as carbonatite.

L. S. Borodin and those with him who decided on the source of carbonatite material had overlooked the fact that the stumbling block is the source of carbon dioxide rather than the calcium (whose presence is unquestionable). That was stated quite convincingly by Eckerman. Moreover, in considering the formation of carbonatites as bodies where calcium is ascendent over magnesium, at the expense of a disintegration of pyroxenes, it should have been indicated just what happens to magnesium which is liberated in this process, in an amount almost double that of the calcium.

In the second place, any conclusions as to the metasomatic origin of ijolites should be based on geologic facts. This process apparently cannot be demonstrated microscopically; even if it were possible to do so, this would not prove

the long transportation necessary for the additional nepheline, because the same effect would be achieved with microscopically small transportation distances. In this connection we must not overlook the arguments on the nature of Witwatersrand gold regarded as unquestionably additive, from microscopic studies by qualified experts, and as placer gold, from quite convincing geologic data. The solutions turned out to be in this very recrystallization of alluvial gold grains, almost in situ [5].

A similar picture may be the true one, with qualifications, with regard to ijolites. This does not mean an out of hand negation of metasomatic rocks with such a composition. They have been observed and geologically confirmed by L. K. Pozharitskaya, E. M. Epstein, and others [8]. However, their role appears to be a modest one; moreover, it is most important to ascertain whether they were the source of carbonatites. On this problem hinges the L. S. Borodin hypothesis and its applicability to the study of such formations.

Finally, if the L. A. Borodin hypothesis is correct, carbonatites may be present only in those intrusions where pyroxenites have been or are present, and ijolites are definitely present. Is that really the case? Undoubtedly, there are massifs with a low, if any, ijolite content, with nothing known of pyroxenites, and with carbonatites present. Some South African massifs are of this type. Whatever the explanation of that phenomenon — we cannot disregard it.

A few words on a feature of these complexes ignored by L. S. Borodin and, apparently, by other petrographers interested in this problem. This feature was noted simultaneously and independently, at the All-Union Conference of Volcanologists (Yerevan, 1959), by Ye. L. Butakova [3] and the present author.

Nepheline-pyroxene rocks are well known among lavas of the alkalic-ultrabasic series. They have been and still are known by different names but their most essential common characteristic is their bimimetic composition. Glass is often absent in such lavas and their mineralogic similarity with ijolites is unquestionable. In addition, tuffs of the same composition are developed along with these lavas.

Thus, by establishing a direct relationship between these and intrusive rocks of the same composition, we acquire the strongest criterion for the origin of ijolites. The Guli lavas of such composition were described some time ago by Ye. L. Butakova [2] and subsequently by A. I. Ivanov [6]. Their mineralogic similarity to Guli ijolites is unquestionable, as far as Ye. L. Butakova is concerned.

The relationship between lavas and ijolite-melteigite series rocks is much better seen in

less disintegrated volcanic apparatuses, such as the Napak in the East African Rift. B. King [9] has shown that it consists of two parts. There is a lava-tuff ring, 20 km in diameter, which constitutes the well preserved outer slopes. This ring consists mostly of pyroxene-nepheline ash, and of some lavas: "nephelinites" (nepheline-pyroxene) and olivine nephelinite. Nephelinite predominates in both lavas and tuffs. This ring is known as the Napak Mountains.

The center of the ring, separated from it by an annular plain, is the Lukopoy Mountain group. It is unquestionably a volcanic neck consisting of an ijolite plug pierced by carbonatites (stock and veins). It is also evident that the neck ijolites and the outer volcanic "nephelinites" are directly related in a common magmatic source.

Thus, a relationship is established in the Napak — Lukopoy example, indicating the magmatic nature of these ijolites, essentially the roots of the lava flows. This relationship is not as evident in the deeply eroded Guli volcano; however, its analogy with the Napak is not to be doubted.

Thus, the geologic picture is as follows:

1) extrusive equivalents of ijolite rocks are widely distributed in ultrabasic-alkalic complexes and undoubtedly are magmatic formations;

2) a relationship between these lavas with ijolite plugs in the craters of the same volcanoes is unquestionable; consequently, these ijolites cannot be regarded as metasomatic, although they are accompanied by carbonatites.

It is therefore quite unlikely that these nephelinization phenomena (occasionally perhaps nothing but a recrystallization of nepheline) are the proof of a metasomatic origin of ijolite. On the contrary, the examples cited suggest an intrusive origin for the overwhelming volume of ijolite. Only an underestimation or neglect of these facts has enabled L. S. Borodin to profound his hypothesis. By the same token, all attempts at explaining the origin of carbonatites in the calcium of pyroxenes should be abandoned. This process cannot be of any importance in ultrabasic-alkalic complexes, nor necessary because the amount of calcium in residual melts is adequate for the appearance of carbonatites.

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CONCERNING V. V. LIPATOVA'S ARTICLE,
"NEW DATA ON THE KAZANIAN STAGE IN
THE AKTYUBINSK AREA OF THE URALS
REGION"^{3,4}

by

M. V. Kulikov

The brief communication by V. V. Lipatova has attracted the attention of investigators on account of its title, which indicates the presence of Kazanian deposits in the Aktyubinsk area of the Urals region.

V. V. Lipatova believes that among previous researchers there has been no uniformity of opinion regarding the stratigraphy of the Upper Permian deposits of the Aktyubinsk Urals. Some (N. N. Tikhonovich, Ye. V. Voinova and others) have considered all the red sediments to belong to the Ufa strata, whereas others (V. Ye. Ruzhentsev, P. I. Klimov) have subdivided them lithologically into three or four suites, which they tentatively correlated with the Ufa, Kazanian and Tatarian stages. According to the latter investigators, continental conditions prevailed here during the Kazanian age. Even before V. V. Lipatova's paper occurrences of pelecypods and ostracodes characteristic of the Tatarian stage had been observed in this territory, but, as V. V. Lipatova says, "either conclusions were not drawn from this extremely interesting and important fact, or else if the fauna contradicted the conceptions of one geologist or another, it was passed off with the observation that the Upper Permian fauna of the Aktyubinsk Urals has been poorly studied and at the given stage could not be used to determine the age of the rocks" (p. 804).

The most complete section through the Upper Permian deposits, in the author's opinion, occurs in the central area of the Urals depression. Within the Western Aktyubinsk and Aktyubinsk-Bishtamak structures, deep drill holes have entered Upper Permian deposits within which, from their macrofauna and microfauna, spore-pollen assemblages and mineral composition

V. V. Lipatova has distinguished the Kazanian and Tatarian stages.

Within the above-mentioned structures V. V. Lipatova assigns to the Kazanian stage four packets of deposits; in the third packet from the bottom, consisting of calcareous-argillitic rock, have been found Dielasma sp. and Sanguinolites lunulatus Keys.

The fourth, or uppermost, terrigenous red packet is composed of sandstones, argillites and siltstones which in color and composition, as V. V. Lipatova mentions, very closely resemble the deposits of the lower packet.

From what has been said here it will be seen that the "Kazanian" deposits of the Western Aktyubinsk and Aktyubinsk-Bashtamak structures are not characterized by fauna, so that there is not sufficient basis for considering them to be of Kazanian age.

V. V. Lipatova states that from west to east the first (red sandy-argillaceous), second (terrigenous with interbeds of limestones, dolomites and anhydrites) and fourth (upper red terrigenous) packets wedge out, and that only the third, limestone-argillite, packet is exposed to the surface at the easternmost points. From this packet of rocks V. V. Lipatova cites the following list of fauna (which I give in its entirety for further analysis): Productus (Linoprotectus) villiersi Orb., Rhynchopora variabilis Stuck., Martinia cf. acutirostris Krot., Marginifera typica Waag., var. septentrionalis Tschern., Marginifera involuta Tschern., Lima kasanensis Netsch., Sanguinolites bicarinatus Keys var. laevigata Lich., Solenomya biarmica Vern. and Palaeoanodonta castor Eichw.

"This third packet was by previous investigators", writes V. V. Lipatova, "erroneously assigned to the Kungurian stage, without taking account of the occurrence of Kazanian marine fauna in the top of the 'Kungurian stage'. Hence it is clear that the occurrences of Kazanian fauna in the lowermost beds of the red-colored strata are fully to be expected" (p. 805).

In conclusion, V. V. Lipatova decides that the Aktyubinsk Urals contain Kazanian marine deposits, within which she distinguishes the above-mentioned four packets.

The assertive tone of this article with its "new data" is based, however, on facts which, whatever the author's desires, testify to something else: to the absence of Kazanian marine deposits and to the fact that the calcareous-argillaceous rocks exposed in the outcrops belong to the Lower Permian.

Such brachiopod forms as Linoprotectus

³O stat'ye V. V. Lipatovoy "Novyye dannyye o kazanskom yaruse Aktyubinskogo priural'ya".

⁴Doklady Akad. Nauk SSSR, t. 128, no. 4, pp. 804-805, 1959.

villiersi (Orb.), Rhynchopora variabilis Stuck., Martinia cf. acutirostris Krot., Marginifera typica Waag. var. septentrionalis Tschern. and Marginifera involuta Tschern. are known only from the Lower Permian of the Urals, but not from the Kazanian deposits of the Russian platform. Moreover in the Lower Permian of the Urals there are no typical specimens of Linoprotodus villiersi (Orb.), but there are varieties of this species, as described in a number of papers by G. N. Frederiks, N. P. Gerasimov, D. L. Stepanov and others. Other species of Linoprotodus have been described by Russian investigators from the Lower Permian deposits on the western slopes of the Urals; in the Kungurian deposits of the Urals the majority are encountered in great number.

Recently R. Ye. Nel'zina has produced a monographic description of the pelecypods from the Lower Permian deposits of the Urals. The species mentioned by V. V. Lipatova have also been found in this assemblage. As early as 1885 P. I. Krotov indicated the occurrence of Solenomya biarmica Vern. in the Artinskian deposits of Mt. Khaldinskiy on the Kos'va River.

In the light of what has been shown here, we cannot share V. V. Lipatova's views regarding the attribution of the calcareous-argillaceous packet with the fauna in the Aktyubinsk Urals to the Kazanian stage. The previous investigators (V. Ye. Ruzhintsev, P. I. Klimov and

others) were correct in assigning these deposits to the Kungurian stage.

V. V. Lipatova's error consists in this, that she has, on the one hand, not taken into account the Lower Permian assemblage of brachiopods, and that she has uncritically made a stratigraphic evaluation of the pelecypods in combination with the brachiopods. The occurrence of pelecypods of the Kazanian type in the Lower Permian of the Urals region is quite common. It indicates merely that these species appeared earlier than we had previously thought.

A considerable fauna has been collected from the Kazanian deposits of the Russian platform. Its composition, particularly as regards the brachiopods, is well known, but up to this time typically Uralian Lower Permian species have nowhere been found in it. Only in the north of the Russian platform, in the Arkhangel'sk area, were chonetids found in the outcrops; as early as 1913 these were studied and described in a monograph by B. K. Likharev. These chonetids, as we have established, were boreal forms that did not migrate to the south of the Russian platform in the Kazanian age.

V. V. Lipatova's remarks again show the need for paleontologists and stratigraphers to turn their attention to the criteria for establishing biostratigraphic boundaries, so as to eliminate errors in determining the ages of rocks containing the remains of organisms.

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